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Future Technology: Targeted Implant Chip for Transcranial Alternating Current Stimulation (TIC-tACS)

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ABSTRACT

Alzheimer's disease is a neurodegenerative disorder and a progressive form of dementia that hinders patients' cognitive functions, causing memory loss, confusion, and brain atrophy. One treatment for the disease is transcranial alternating current stimulation (tACS), which stimulates the degenerating parts of the brain using low-intensity electrical currents. Currently, tACS is applied solely through external machinery. This paper will propose and discuss the implications of one type of novel innovation, which has not yet been created, designed to mazimize patient comfort. The Targeted Implant Chip with Transcranial Alternating Current Stimulation (TIC-tACS) device will be a compact self-contained unit capable of applying tACS through electrodes while granting the patient unparalleled mobility and freedom. TIC-tACS will help relieve symptoms and improve quality of life for Alzheimer's disease patients.

Introduction

Present Technology and Limitations

Today, there are ways of lowering the lasting effects of dementia. However, these methods are not foolproof as uncertainties still exist and technology is not fully developed. Methods and specific processes such as deep brain stimulation (DBS) and transcranial magnetic stimulation (TMS) are both used today, but they are not reliable for regular usage, and their results are not consistent. Other limitations include the dangers of surgery, the safety of microchips, and the lack of research.

Deep brain stimulation, a method where a surgically implanted system sends electrical pulses to the brain, includes many setbacks regarding safety and the working age range in terms of dementia [1]. To expand, DBS has been used to treat conditions such as Parkinson's disease, epilepsy, and other movement-related diseases. When the DBS device is surgically implanted into the brain, it is made to control neuron activity through the usage of internal pulse generators to electrodes to target certain areas. The amount of stimulation that the electrode sends is managed by the internal pulse generator that is positioned under the patient's chest, which is connected by a wire that passes down the neck and shoulder.

However, there are certain risks associated with DBS, such as the body rejecting the device and postsurgical concerns [2]. Because DBS requires an artificial implant under the chest, the insertion and removal of this would be more challenging and may cause complications. These complications include infection, stroke, and headache. There is also a possibility that the device malfunctions. For example, the lead wire could erode, which would lead to inflammation, swelling and pain at the implantation area.

Researchers also have not yet to find the best location in the brain for the treatment, which means that more research must be conducted. To connect DBS with dementia such as Alzheimer's, this treatment only works for early stages. As it targets motor functions, once a patient becomes old and has more moderate to

severe dementia, DBS cannot reverse movement loss. Therefore, deep brain stimulation is not the best option for dementia as it can only be used in such a narrow time frame, and the results may not be consistent or long-term.

Another technique used to treat dementia is transcranial magnetic stimulation (TMS). During a session of TMS, an electromagnetic coil is positioned against the scalp, close to the forehead [3]. The electromagnet sends a magnetic pulse that causes nerve cell stimulation. It is also commonly used to treat depression as it activates areas in the brain that involve mood control.

However, due to TMS being a treatment where improvements happen per session, this could be timeconsuming for the patient. Most sessions may last up to forty minutes for five days a week, which is hard to keep up with [4]. Some patients may not have access to a nearby hospital or facility that allows this treatment, let alone have time on the weekdays. It is also an external technology that takes up a lot of space and is not convenient. For dementia patients, TMS has been growing in terms of a possible treatment, although many aspects of it are deemed unknown or undetermined. For example, there has not been much research on TMS's influence on Alzheimer's disease pathogenesis. Similar to DBS, there are also age restrictions. Even if TMS is effective on young adults, the same process applied to elders may cause harm [5]. The TIC-tACS device will surpass these limitations, and sustain the needs of dementia patients.

History

Transcranial alternating current stimulation has its origins in the field of electroconvulsive therapy (ECT), a medical procedure that uses electrical currents on the patient's brain in order to deliberately cause seizures. First developed by Italian psychiatrists Ugo Cerletti and Lucio Bini in the 1930s, ECT was used as a treatment for conditions including severe depression and schizophrenia. In the 1940s and 1950s, ECT spread like wildfire and was used all across the world. However, due to worries about its effectiveness and safety, as well as side effects like memory loss and cognitive impairment, its use greatly declined in the 1960s and 1970s [6].

Researchers started testing more focused types of brain stimulation in the late 1990s, including transcranial direct current stimulation (tDCS) and transcranial random noise stimulation (tRNS). These methods, which are able to target specific brain regions, use electrical currents of lesser intensity and frequency than ECT. tACS specifically is a form of brain stimulation that modifies brain activity by applying alternating currents as opposed to direct or random currents. Otto Creutzfeldt carried out the first study employing tACS in 1962, but it wasn't until the 2000s that the field of science started to pay greater attention to the technique [7]. Numerous studies have looked into the possible applications of tACS in recent years, including enhancing cognitive performance and memory loss. The same issues caused by ECT are now being treated with its successor, tACS.

For tACS to be applicable through a portable device similar to a pacemaker, the technology must be shrunk to a smaller size, and the newest technology in shrinking microchips is the one-dimensional helium model system. The first demonstration of this system, while fairly recent, is essential to note as it fundamentally changes the entire microchip industry for the years to come. In July 2022, physicists developed a new method of assembling microchips that allows for less physical space in between the components of a microchip, allowing for smaller technologies. According to Paul Sokol, a professor at the IU Bloomington College of Arts and Sciences, "it's like confining the electrons in a one-dimensional tube, and that behavior is quite different from a regular wire" [8]. However, this newer development is a direct result of preceding innovations. Historically, various alternative methods have been utilized as well, such as adding patterns that interweave onto a pre-shrunk silicon wafer. The microchip itself was initially developed by Jack Kilby in 1958, and with the help of Robert Noyce, the pair laid the foundations for new chip-shrinking technologies [9].

Proposal

Mechanism and Execution of Device

This technology will be a self-contained unit capable of applying transcranial alternating current stimulation to a patient without the need for an external regulator or power source. This allows the patient unparalleled mobility and freedom, able to receive the treatment they need without being confined to a hospital bed and connected to large machinery. The TIC-tACS device will be small enough that it can administer a preprogrammed current of tACS in a self-contained unit while still not interfering with the daily life of the patient. In order for such a device to be created at such a small scale, one-dimensional helium modeling will be used. In order to use 1-D helium modeling to make a small device for tACS, the microchip would first be modeled using computer-aided design (CAD) software. This design would be used in the helium modeling process by nano-engineering a material composed of glasses with pre-existing one-dimensional channels and creating a coat on them with an element such as argon to make a narrower channel. Researchers could subsequently make samples that would hold large volumes of helium and support the use of neutron scattering to load detailed information onto the system, essentially pre-programming the chip with the ability to produce a stimulating current, something that can currently only be done by implanting a second device in the chest for DBS [10].

The portable nature of the TIC-tACS device will allow it to be placed in a customizable location comfortably for the patient. This may be the top of the head, the scalp, the base of the neck, or wherever the patient requires. The electrodes on the device (as visible in Figure 1) will run out from the unit and be secured in place internally with dissolvable sutures. The power will come from a long-term lithium-iodide battery, similar to those used in pacemakers, that converts chemical potential energy into electricity for the currents. The TIC-tACS device's portability allows for further specialization, allowing a physician to place the electrodes in specific locations to target isolated areas of the brain. A physician will also be able to pre-program the device's current, allowing for a select frequency, magnitude, and wavelength for the current. The TIC-tACS device can also be altered to be more direct, alternating, pulsed, or even random, unlocking the full potential of current stimulation.

The stimulation will be administered using electrodes on the surface of the device to deliver a small current to the scalp. Specifically, the TIC-tACS device will be equipped with both cathodal and anodal stimulation for a combined effect, where the hyperpolarizing effect of the cathode augments the depolarizing effect of the anode. An electroencephalogram (EEG) will be used to measure the patient's brain activity and determine what areas of the brain are low in activity. Alzheimer's disease and dementia often see degeneration in the medial temporal lobe. Therefore, possible target locations for the anodal tACS might be the fornix, hippocampus, or dorsomedial prefrontal cortex. The target anodal electrode will be placed in the low-activity sector of the brain, the cathodal reference electrode is placed in the contralateral hemisphere. This dual method of stimulation will directly augment brain activity in the patient and additionally promote the construction of new neural pathways between the areas of consideration.

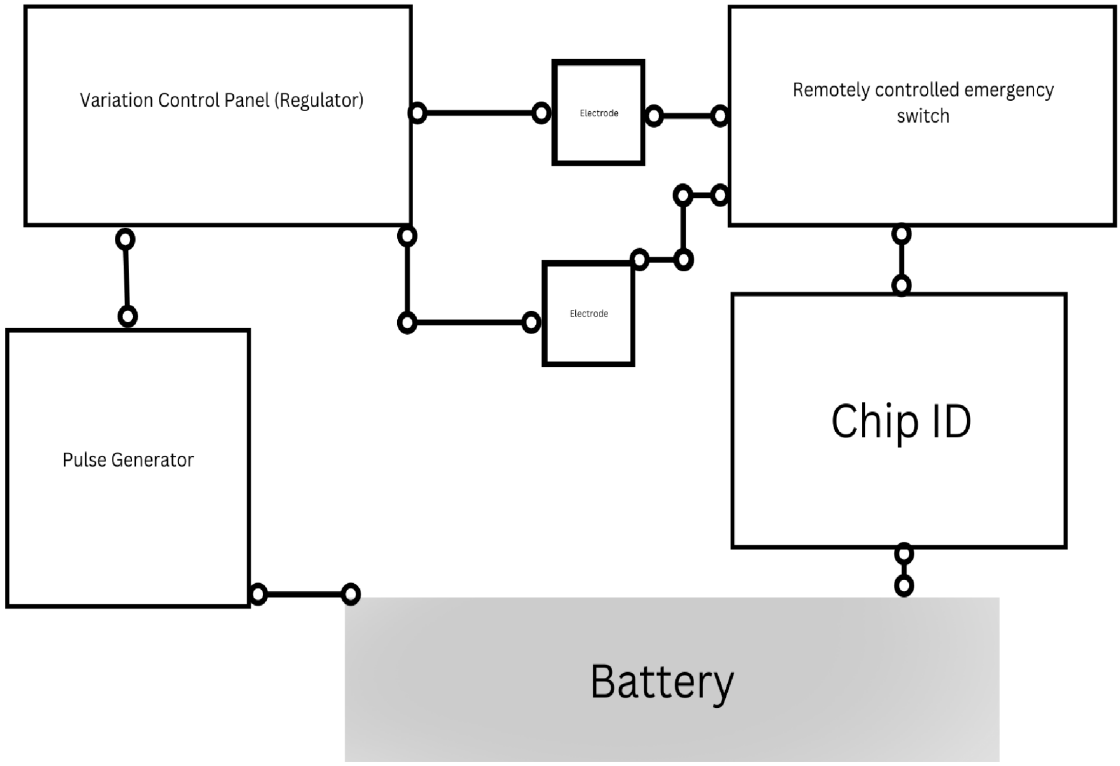

Figure 1.

Breakthroughs

The breakthroughs required to make our device happen include three factors: a safe, risk-free implant for the body, a condensed, small enough system to fit in the brain, and the innovation of a less invasive surgical procedure.

Safety for the Body

In order for the device to be safe for the body, the risks must be small, and the side effects must be as preventable as possible.

Side effects occur when the body rejects the procedure that has been operated on. This happens when the body reacts irregularly to any medical procedure or pharmaceutical medication. While most side effects are generally resolved in a few weeks or once someone stops participating in a procedure, the adverse effects of an implant can be potentially life-threatening [11]. Especially when dealing with new technology, it is vital to carefully devise a procedure and implant in a way that keeps the patient from harm. Although we can implant certain devices in the current day, the control system for DBS is often placed under the collarbone surgically; in the TIC-tACS device, the goal includes condensing the system to just a chip, which would involve making sure that all parts of the control system are also safe for the body.

A Condensed System

To condense the device and make it small and easy to implant, we can create a microchip that will be less invasive while still maintaining functionality. Compared to technologies that are either external and inconvenient or require many internal surgeries in multiple parts of the body, the microchip would only be inserted into the brain and target the specific region required to deliver electrode currents by using tACS.

However, at the moment, chip vulnerability is a major concern in terms of having microchips widely used. There are possibilities where tracking may be involved, which could potentially harm the patient and cause further problems than just health-related ones [12].

To expand on the problem with current technology, leadless brain implants such as microchips demonstrate risks such as movement within the cranium. These risks have the ability to harm or reduce the working life of the chip. Also, in order to perform an implantation this specific, extra measures must be taken in terms of precision, meaning that any uncertainties must be resolved before the TIC-tACS device is created. Our goal is to produce a microchip that can be implanted without having to be removed for its adverse effects or rejection, which is only plausible with the technology of the future such as the ability to shrink the pulse stimulator itself into a small enough device that can be safely implanted.

Less Invasive Surgical Procedure

To prevent the intense surgical procedure that is required for any implant in the present day, we would need to develop less invasive surgical procedures. In order to begin to test our project, we would first need the scientific world to accomplish a breakthrough in still-developing technologies such as laser and robot-assisted surgeries that would allow for the delicate surgical procedure that this project requires to be accurately performed. Because the microchip is so small, precision is key, and that is a major breakthrough that we will certainly be closer to achieving ten years into the future.

Design Process and Procedure

Before settling on this design, we considered many unique alternatives. These designs were less invasive, but on the net, they were also less effective and did not solve some of the target issues that we were attempting to address.

Initially, we wanted to create a wearable device, such as a headband which would have a control system embedded within it and have electrodes attached that could discreetly be placed upon the scalp under the fabric. However, with this design, there were many practical complications when the device was placed into the context of daily life. Because the device is sensitive, it would not be able to withstand even the most common weather events such as rain or windy days, and extreme temperatures could potentially hinder its process by breaking it down and diminishing its function. Additionally, the device would bear the risk of slipping off or being misplaced, and consequently, patients would be forced to exercise great caution at all times. Also, any malfunction would be difficult to detect and troubleshoot for the user. Furthermore, patients would be self-administering the process: something that people of every stage in dementia are capable of doing. In contrast, our design maintains its temperature due to the natural homeostasis of the body, and as an inserted device, it remains unaffected by most forms of climate events or physical activity.

Another one of our original designs included the use of a minimized version of DBS which employed electrodes that could be placed just under the skin, targeting peripheral skin nerves rather than brain neurons. This design would have allowed us to bypass the issues of portability and temperature maintenance. However, this design had its own challenges. For one, there is limited research on the impacts that subcutaneous stimulation can have in the long term. It is also not well understood if subcutaneous stimulation only works for certain people, as so far, the process is so new that the success rate is not quantifiable. For example, a 2003 study on the effects of transcutaneous electrical nerve stimulation found that “sufficient data could not be obtained as… no effect of TENS was found” [13]. This lack of understanding already presented a primary obstacle in the

development of the design, and furthermore, subcutaneous implants can make patients more subject to discomfort or adverse side effects.

A third major design idea that we ultimately chose to forgo was a microchip implant that utilized tDCS instead of tACS. While tDCS is a useful and effective technology that modulates the excitability of the cortex, tACS is known for its use of an oscillating current that can modify specific electrophysiological rhythms selectively. Because tACS provides medical professionals with the ability to target specific regions of the brain and alter the activity there more accurately in comparison to the more general excitation provided by tDCS, in the end we chose to execute our research and project on our current topic: an implantable microchip that employs tACS.

Implications and Conclusion

All scientific discoveries can have great ripple effects across society; as a result, there are various positive impacts of this project on the healthcare industry. Current treatment strategies for neurodegenerative diseases are plagued with long wait times, pocket-emptying costs, and debilitating side effects. Often patients lose their autonomy and are forced to rely on family members or loved ones who they do not want to burden. As a result, with this innovation, we attempted to focus our goals on providing patients with the greatest quality of life and autonomy that they could possibly achieve following a dementia diagnosis.

The pros of this technology include greater effectiveness, fewer obstructions to daily life, and reduced maintenance required to keep the treatment functioning. Even recovery times from the procedure and costs would be decreased subsequently to the release of a tACS microchip because unlike current treatments such as DBS, an implanted titanium-alloy microchip would be much smaller and easier to implant, reducing the risks of rejection from the body and the need to perform multiple incisions to attach the system to the patient. Furthermore, the TICtACS device allows a patient to live similarly to their pre-diagnosis life by being free of adjustment-requirements or frequent visits to a clinic. As a one-time procedure which then only requires intermittent medical check-ups to ensure that everything is running smoothly, a TIC-tACS implant would cut costs and readjustment periods that often follow the current treatments which need to be performed regularly for months before even the opportunity for improvement arises.

Inevitably, any innovation brings its own challenges, especially one in the healthcare industry. Because this device is surgically implanted, it would hold the inevitable risk of rejection from certain patients' bodies. It is also important to note that the creation of the TIC-tACS device would require many breakthroughs technologically, which would likely inflate the price exponentially. However, as easier methods of production are developed, this cost would eventually balance out and cost less than frequent treatment and visit co-pays. Simultaneously, another negative consequence would include the moderate recovery period for the procedure of introducing this device to the body. There are limited risks associated with post-operational recovery, but even these minor side effects can be challenging for patients with conditions such as dementia; in those times, it would be vital to have a caretaker, which is not a luxury that everyone would be able to afford.

While there are many positive and negative implications of the development of our innovation, the net impact of the creation of the TIC-tACS device and procedure would fundamentally alter the way healthcare views neurodegenerative diseases, kindling new developments and research in treatments for what is currently a gamble in a healthcare lottery.

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