# Ethical Implications of Hippocampal Prosthesis to Improve Memory

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## Abstract

The hippocampal prosthesis is a relatively new development in the field of neurotechnology. For this reason, researchers and neuroscientists are not entirely optimistic about the problems that could arise in the future regarding this technology. This new advancement could significantly impact the future if applied correctly. Ethical considerations should be explored and addressed, allowing a smoother journey into refining and improving this technology. Patients with Alzheimer’s experienced extreme amounts of emotional distress during their periods of degeneration due to isolation. Until now, there have been few possibilities for improving their cognition. The hippocampal prosthesis allows them to regain memory and interact with each other. However, there is a gap in whether unexpected scenarios were to arise, causing problems for the safety of the patient's privacy, finances, identity, and even life. Possible solutions to each situation must be well thought out and accounted for. This paper addresses the ethical considerations for patients using this hippocampal prosthesis to treat Alzheimer’s. This will be done by looking at how the prosthesis will be inserted and what will occur once the prosthesis replaces the atrophied Hippocampus. Then, proposals for ethical considerations will be discussed. It is important to address known areas of the hippocampal procedure in further research. Speculative situations, which are not widely scrutinized, should have possible courses of action if the hippocampal prosthesis does not perform as expected.

## Background

How can safety protocols and ethical considerations be enforced when inserting a prosthesis for the hippocampus to improve memory in patients with diseases such as Alzheimer's*?* To safely implement a Hippocampal prosthesis into a patient with Alzheimer's disease, ethical considerations such as affordability, privacy, identity, and risk assessment need to be addressed to prioritize patient welfare. Despite these technological innovations to increase human well-being, one of the few persisting questions in the 21st century remains: is there a cure to memory-loss diseases such as Alzheimer's and dementia? The answer seems to loom in the hippocampus. Found in the inner folds of the temporal lobe, the hippocampus is an important part of the limbic system, which is part of the cortical system and regulates motivation, emotion, learning, and memory (Ajmera, 2023). When the hippocampus is damaged due to disease or injury, a person may experience memory loss or other cognitive impairments.

One of the main purposes of the hippocampus is to help humans process and retrieve two types of memory: declarative memories and spatial relationships (Ajmera, 2023). While declarative memories are more related to rational decisions and events like learning to memorize certain events, spatial relationships focus on accumulated thinking on entities like routes throughout a city. As such, the hippocampus plays a vital role in spatial memory and navigation, converting short-term memory into long-term memory, and regulating motivation, emotion, and learning. Based on that, whenever neurodegenerative diseases like dementia ravage one or more parts of the hippocampus, the individual can lose certain memories or, in worst cases, could even lose the ability to make new long-term memories.

In recent years, researchers have explored the possibility of using prosthetic devices to help restore brain function. Neuroprosthetics is an evolving field of neurotechnology that aims to repair various facets of cognitive function by repairing damaged brain sections with prosthetics. Neuroprosthetics are bioelectric devices that stimulate specific structures within the nervous system to reestablish certain neural networks and bridge oscillations as an alternative to pharmacological treatments (Gupta et al., 2023). When paired with specific frequencies, certain oscillations help restore the connection between two different areas. Developing a prosthetic hippocampus that is wired into the damaged hippocampus can create a mechanical bridge between it and the brain, mitigating the severe effects of brain degeneration and enhancing cognitive function in retaining new information (Hamzelou, 2022).

The developed hippocampal prosthetics replaces the missing function of damaged neurons in the hippocampus by taking in input from the hippocampus, predicting the standard output of the hippocampus, and finally, firing out this output for long-term memory retention. It comprises a prosthetic neuronal memory chip with a multi-input/multi-output (MIMO) nonlinear train. The device imitates a neuron: it communicates via mathematically derived replicated spatio-temporal patterns, by making predictions from CA1 and CA3 and stimulating and providing predicted outputs, usually in the form of memories (Berger et al., 2012). Researchers have used this device on rats (Hampson et al., 2012) and the experiment shows promising results that could allow neuroscientists to further experiment with humans who deal with amnesia or Alzheimer's. In addition, a study was conducted in 2018 to assess the effects of hippocampal prosthetics on epilepsy patients (Hampson et al., 2019). The deep electrodes were surgically inserted into the volunteer subjects. They were shown to hold promise in improvements in short-term and working memory that may be refined and applied to Alzheimer's or amnesia patients.

In conclusion, while the development of hippocampal prosthetics offers remarkable promise for restoring memory and cognitive function in patients with neurodegenerative diseases, it is essential to address the accompanying ethical, safety, and societal challenges. Continued research and careful consideration of these factors will be crucial to ensuring that such innovative technologies can be safely and equitably integrated into clinical practice, ultimately improving the quality of life for those affected by memory-loss disorders.

## Rationale

This paper aims to consider and discuss uncovered ethical implications and refine previously covered implications that would arise and are important to address with the clinical usage of Hippocampal prosthesis (HP), specifically for neurodegenerative diseases. With this idea in mind, creating neuroprosthetics for the hippocampus will also allow electronic devices to register and process neuronal signals and to adaptively stimulate damaged brain areas according to the online algorithm for people with Alzheimer’s disease. The closed-loop connection between two hippocampal neuronal networks will help restore functionality of damaged areas in the brain to replace lost functions in patients with neurodegenerative disorders.

## Neuroethical and Social Implications

### Financial Availability

While this new technology is promising, some ethical issues must be addressed. Due to human variability in brain structure and function in each hippocampus, each prosthesis must be tailored to a specific size and shape according to the patient. Functional magnetic resonance imaging (fMRI) can be used to measure the volume of the diseased hippocampus as a noninvasive option to tailor the prosthetic to the precise measurement of the patient's hippocampus. Although there is no accurate approximation for a price tag for this procedure, it can be reasonably deduced that it will be costly. Therefore, the technology poses problems regarding availability to low to mid-income families due to the high expenses needed to construct and personalize each hippocampus prosthetic to fit into a specific individual. A possible way to help fund the technology is to search for grants from government and nonprofit organizations, such as the Alzheimer’s Association, to aid low-income patients in getting the procedure done. Additionally, insurance does not currently fund long-term care for patients with Alzheimer’s disease. This means that patients who necessitate continued care for their health are currently denied it due to the policy. Conversely, insurance does aid with short-term care for Alzheimer’s, such as this procedure, meaning that the price of the treatment will also drastically reduce compared to long-term remedies.

**Cybersecurity & Memory Corruption**

Another ethical issue is the possibility of a third party introducing false memories in the artificial hippocampus by altering certain memory codes produced via MIMO (Berger et al., 2011) through a cyberattack, causing the patient to analyze and interpret the misinformation with the prosthetic. If the patient was a witness or victim to a crime, the offender could use these codes to change how or what details the patient remembers and can completely alter memories of the situation. This could result in the offender walking away from the crime scene with no charge and an overall injustice in the justice system. Although altering codes on this memory prosthetic is a difficult task, as there would already be security measures in place to hinder any breaches, with the ever-increasing field of cyberattacks, it is best to be prepared for these situations. This is due to the electrical signals being transmitted into such devices as the MIMO chip, which can be stored and recovered for later usage, and replace the function of traditional memories with digital code (Berger et al., 2011). To avoid this situation, files on everything the person experienced that have been saved in this artificial hippocampus or long-term memory should be encrypted. Any information processed using the prosthetic will be transferred to a central data center.

Continuing to expand on this issue, people may feel unsafe releasing their data for tracking. However, this is a solution to ensure the accuracy of the patients' memories. Certain services, such as AWS, Google, and Azure, protect their consumer data through specific cybersecurity measures to prevent this data from being stolen or hacked. First, the data is broken up into chunks and then encrypted with its data encryption key. To provide extra security if someone receives or discovers the data encryption keys, each can be wrapped using a key encryption key, which is then stored in a secure company storage infrastructure. Even with this extra security, the data could still be hacked and sold by external parties who could steal the patient's identity. In most research, patients need to be identified by giving a corresponding number, so their personal information, like their date of birth and social security number, is not out in the open and accessible through the central data center.

**Patient Safety**

With no confirmed power supply to the prosthetic, the implant must be removed to be recharged occasionally. This would result in invasive surgeries every two to three years because of the high energy consumption by brain stimulators. Too many surgeries could result in postoperative cognitive dysfunction (POCD) and reduced cognitive functions, especially in elderly patients (Rudolph et al., 2010). Worsened cognitive ability functions could also result from going under anesthesia too many times. To prevent this, it is vital to figure out how to create a self-charging battery or a similar device that works so that surgeries will not be needed every so often. Another adverse effect is that a lot of scar tissue would build up around the head, resulting in possible hair loss. However, one potential solution for this debacle involves utilizing piezoelectric energy that can convert biochemical pressure found in the cerebrospinal fluid (Beker et al., 2017) or other materials (Marino et al., 2017) surrounding the brain into electrical energy. These transducers could be integrated into the hippocampal prosthesis, tapping into the brain's resources to power the device continuously in order to help with cognitive function.

**Memory Enhancement in the General Population**

The Defense Advanced Research Projects Agency has taken a particular interest in a Human Memory Prosthesis to help military personnel with brain injuries or illnesses through a program called Restoring Active Memory (RAM) (DARPA) Their process involves surgically implanting electrodes to record neural activity in the hippocampus, specifically the CA1 and CA3 regions of the hippocampus proper, in those with epilepsy. Neurons in the CA3 region fire when the brain identifies information that needs to be stored as memory, which is then transmitted to the CA1 region, the output of the hippocampus. Using MIMO modeling, the team effectively designed a program that essentially bridged the gap by predicting the transformation of the CA3 neurons, correlating with the CA1 firing patterns. The results from the stimulation showed that it did not replace "normal" CA1 activity but instead supplemented it. This means it acts as a metaphorical steroid for the hippocampus, raising more questions than it might answer. The volunteers from the program displayed a 35% increase in memory over average, a significant rise (DARPA). However, the way this procedure is implemented, it can be done on any human, regardless of age, race, or mental illness. Going through this procedure on a "normal" human poses questions about whether one can use this procedure for personal gain and increase memory capabilities. Moreover, if taken in the classroom, similarly to other brain modulation technologies, what does that mean to others who do not choose to get the procedure if taken in the classroom, similar to other brain modulation technologies?

## Conceptual Challenges

### Obstruction of the Regeneration of Neural Brain Cells

Implanting a foreign body, the hippocampal prosthesis, may lead to the disruption of cytokines and chemokines. Specific cytokines, specifically the increases in IL-1β activation, possibly lower the boundary between neurotoxicity and magnify neurodegeneration response (Kozai et al., 2014). Additionally, the MMP-9 protein is shown to be increased during the following weeks of neuro implantations. Increased response of MMP-9 can lead to the degradation of various cellular structures, including the extracellular matrix and certain proteins (Kozai et al., 2014). Knowledge of the effects of the hippocampal prosthesis is limited since it is a relatively new development; for this reason, it is important to be vigilant about inserting the implant.

### Insufficiency in Substantial Improvements and Misremembering

Implanting a prosthesis in the place of the hippocampus may not be sufficient to create substantial improvements in memory. The amygdala, the cerebellum, and the prefrontal cortex are all structures associated with memory. Memory degeneration diseases affect these brain regions, meaning implanting a prosthesis in one part of the brain may not solve the issue entirely or as successfully as people need. Due to how memories are stored in code with a prosthesis, misremembered memories could unintentionally influence incorrect data into the MIMO chip, permanently changing their memories due to misremembering. This can cause large amounts of distress, as misremembering is very common in humans and could cause rapid destruction of memory.

**Surgical Risks**

Implications regarding protocols for the patients should be considered. Hippocampal transplantation is a complex undertaking, possibly causing greater amnesia in Alzheimer's patients. Since the insertion of a prosthesis to replace the hippocampus is a highly invasive operation, going askew could result in life-threatening situations. Regardless of the operation, inserting an implant will tear through the extracellular matrix, disrupt the blood-brain barrier (BBB), puncture cell membranes, and even rupture distant cells (Kozai et al., 2014). The disruption of the BBB and the insertion of implants have been shown to alert nearby microglia momentarily. Other consequences associated with the penetration of brain implants are that they cause stress due to the volume they take up in the brain tissue. The effect of the implantation volume gives rise to other factors that should be considered, such as disrupting blood vessels and causing intracranial pressure (Kozai et al., 2014). After taking all of these risks into consideration, strict regulations must be put into place and further research must be conducted to ensure the safety of all patients.

## Conclusion

In recent years, new atypical treatments for irreversible Alzheimer's and memory-related disorders, such as dementia and amnesia, have arisen. One such astounding research has occurred for the hippocampal prosthetics, a novel solution to the Alzheimer's, dementia, and amnesia crisis. However, while the concept of hippocampal prostheses is promising, significant challenges remain in their development and implementation. The brain is an incredibly complex organ, and achieving seamless integration between the prosthetic device and the neural tissue poses substantial technical and ethical challenges. Ethical concerns regarding privacy, consent, and potential alterations of personal identity also need to be addressed before widespread adoption of hippocampal prostheses can be considered. Striking the right balance between medical benefits and possible risks is crucial for responsible and safe implementation. Despite these challenges, ongoing research and technological advancements are likely to push the boundaries of hippocampal prosthesis further to make the benefits more worthwhile, such as hypothesized treatments for PTSD, hippocampal trauma, and epilepsy. Continued collaboration between stakeholders, neuroscientists, engineers, healthcare workers, and, most importantly, ethicists will be essential to overcome hurdles and ensure the technology's safe and effective use. Only then can the full potential of hippocampal prostheses be harnessed to understand and augment human memory function.

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