Brain Implants - An Overview on the Advancements and Neuroethics

A Literature Review from a Bio-Electronics Standpoint

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***Abstract*—**The use of artificial devices to control the functioning of various parts in a human being has seen an upsurge in the last decade, which has led to voluminous deliberations and skepticism. This paper presents an exhaustive discussion of several experiments conducted on brain implants, their results, research gaps, possible future advancements and the neuro-ethical vantage point for continued usage of brain implants in patients.

1. INTRODUCTION

Brain implants, often referred to as neural implants, are tremendously powerful medical tools that are con- nected directly to the brain - usually placed on the surface or attached to the cortex. These implants interact with the brain by sending pulses of electricity to neurons, thereby overriding native firing patterns and forcing them to communicate in a different manner. Neural implant is regarded as a hack into the nervous system. Implants like Deep Brain Stimulation (DBS) and Vagus Nerve Stimulation (VNS) (Figure 2) have increasingly become a routine for patients with Parkinson's disease (PD) and clinical depression, respectively. As of 2018, there are more than 150,000 people globally, with a DBS implant, of which, North America holds the lion's share in the market.

2. KEY DEFINITIONS

- **Cortex-** The outer layer of the cerebrum (the cerebral cortex), composed of folded grey matter and playing an important role in consciousness.
- **Basal Ganglia-** A group of structures linked to the thalamus in the base of the brain and involved in coordination of movement.
- **Percutaneous site-** It is a site where access to inner organs or other tissue is done via needle-puncture of the skin, rather than by using an "open" approach where inner organs or tissue are exposed.
- **Simultaneous bilateral implant procedure-** This procedure involves 2 sequential implants in each of the hemispheres of the brain.
- **Subthalamic nuclei-** It is a small lens-shaped nucleus located ventral to the thalamus and is a major part of subthalamus. It is an important modulator of basal ganglia output.
- **Astrocyte-** a star-shaped glial cell of the central nervous system.
- **Iatrogenic-** Due to the activity of a physician or therapy. For example, an iatrogenic illness is an illness that is caused by a medication or physician.

3. METHODS AND MATERIALS

A. *Deep Brain Stimulation*

DBS (Figure 1) is an effective neurosurgical procedure to treat Parkinson's disease which is caused by the inactivation of basal ganglia in the brain. Neurostimulators like micro-electrode arrays are implanted, which send electric pulses to specific targets in the brain. Utah array (Figure 3) which is made up of Pt-Ir alloy for bi-directional signalling proved to be a quantum leap in the domain of electrodes.

B. *Stentrode*

A realm of implants called Stentrode, are stent-like electrodes that are injectable electronic mesh, made up of silicon nano-electronic thread. These are infused into the body as a liquid which then hardens into a stretchy taffy-like substance. The device records and streams the activity of neurons, wirelessly. Stentrode (Figure 4) is implanted in the blood vessels of the brain associated with movements, which eliminates the need

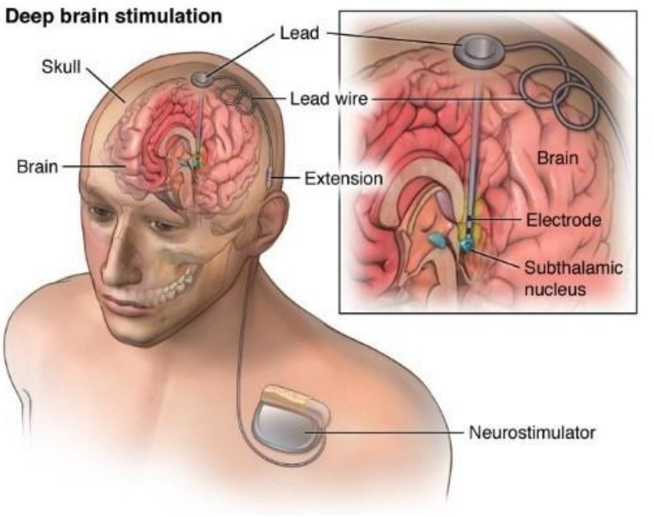

Fig. 1. Lead is a thin, insulated wire inserted through a small opening in the skull and implanted into a specific brain area. The extension wire is also insulated and passed under the skin of the head, neck and shoulder, connecting the electrode to the Internal Pulse Generator (IPG), which is the third piece of the system and is usually implanted under the skin in the upper chest.

of implanting the traditional arrays through an open skull surgery. Synchron [6] is a company that develops such devices for severe paralysis patients. A DARPA funded research team has developed a technology under their RE-NET program in which, the stentrode is delivered via catheter angiography - a much lower-risk procedure [2]. The catheter is inserted into a blood vessel in the neck. Researchers then use real-time imaging to guide the stentrode to a precise location in the brain, where it then expands and attaches to the walls of the blood vessel to read the activity of nearby neurons. This minimally invasive device shows potential as neural interface for brain.

C. *Bioresorbable implants*

The term bioresorbable (Figure 5) refers to something that can be broken down and absorbed by the body. A new class of thin, electronic sensors that are smaller than a grain of rice, are built on extremely thin sheets of dissolvable silicon which can monitor temperature and pressure within the skull after a brain injury or a surgery, then melt away when they are no longer needed [5]. This eliminates the need for additional surgery to remove the monitors, thereby reducing the risk of haemorrhage. This technology can be used for electrical stimulation and drug delivery system with profound trials and improvements in the future.

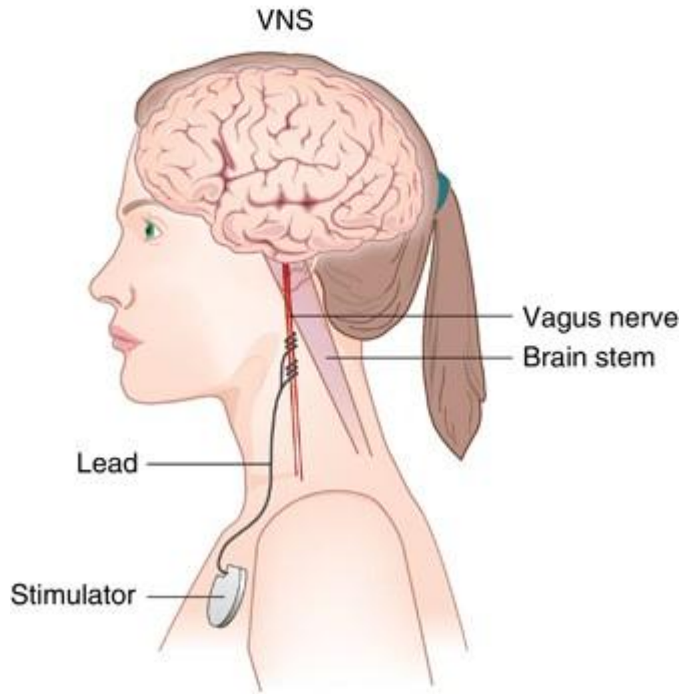

Fig. 2. The treatment consists of a pacemaker-like device implanted under the skin in the chest that delivers regular, mild electrical pulses to the brain via the left vagus nerve.

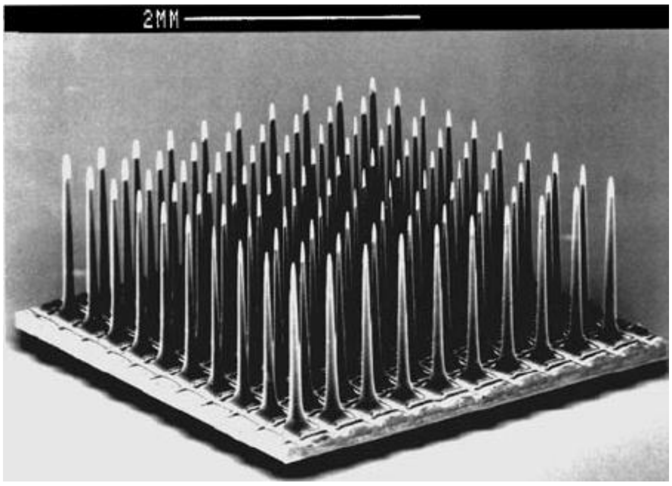

Fig. 3. The Utah Electrode Array (UEA) - It shows 100 micro- electrodes in a 10 X 10 configuration projecting out from its silicon base. Each electrode is separated from its neighbors by 400 microm- eter and is electrically isolated from its neighbors by a moat of glass surrounding its base. Each electrode has a lead wire bonded to its base (not shown).

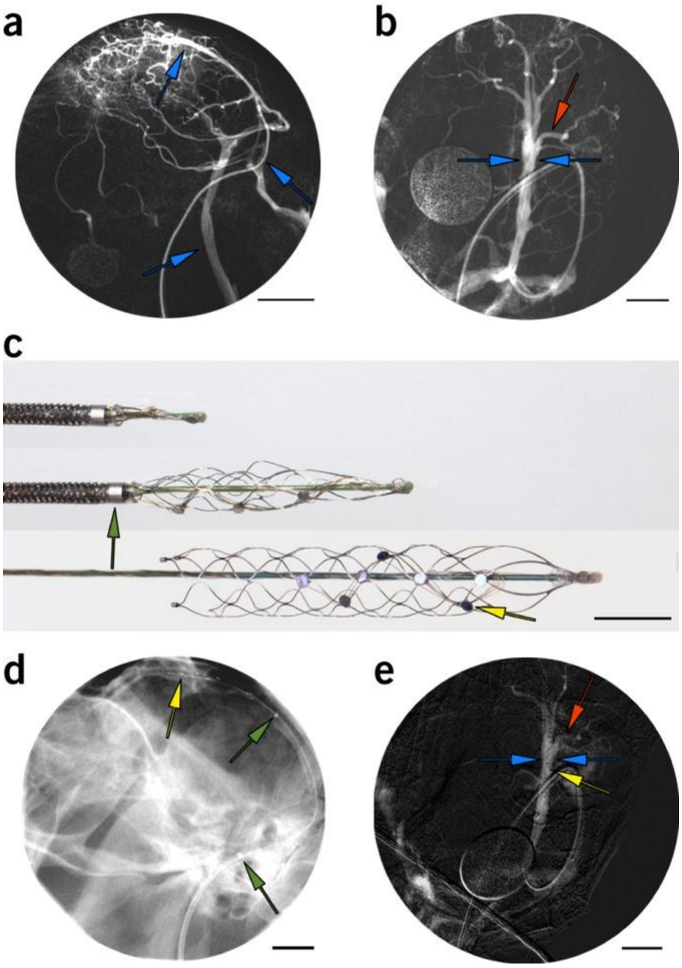

Fig. 4. Stentrode consists of a 3 centimeter-long, 3 millimeter- wide mesh tube made from a nickel alloy called *nitinol*. Its net-like surface is then covered in an array of electrodes, with each electrode registering the activity of around 10,000 neurons.

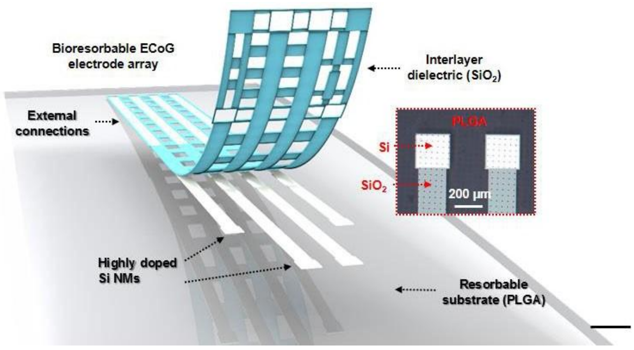

Fig. 5. The silicone/molybdenum electronic devices built by John

A. Rogers of University of Illinois Urbana - Champaign in flexible electronics. The thickness of the final product determines the time it takes for them to dissolve and so they can be prepared for specific clinical applications.

4. Literature review

- A 96-day study was carried out from March 14 through June 18, 2002, in England and the United States by Kevin Warwick; et al, that addressed a major issue which is, the possibility of infec- tion occurring because of the implants [4]. Tissue around wounds, especially in percutaneous site was monitored closely for efflorescence. To reduce the probability of infection, only 20 of 100 electrodes on the implant array were connected, thus, reducing the diameter of the wire bundle exiting the arm. After the study period, there was no indication of infection and no signs of implant rejection by the body at the time of removal. Instead fibrous scar tissue was seen growing around the implant site, holding it in position. The robustness of the array could be seen when all 20 electrodes and 2 reference wires were fully functional during the time of implantation whereas, only 3 electrodes remained functional at the end of the study due to the discontinuity and non-functionality of the electrodes.
- Erich Talamoni Fonoff; et al, conducted a research on 57 patients with movement disorders who under- went bilateral DBS implantation in the same study period [3]. The major conclusion drawn from this study was that simultaneous bilateral implantation procedure is significantly faster and better tolerated by patients than the traditional approach of sequen- tial electrode implantation.
- Swiss researcher Daniel Waldvogel, MD, of the University of Zurich, and co-authors, identified 9 proficient swimmers who continued swimming even after they were diagnosed with PD [10]. 3 out of 9 patients were found to have an impairment in the swimming skills after the DBS was implanted in subthalamic nucleus. The limb co-ordination improved and their ability to swim came back immediately after the patients tried switching off the DBS.
- An empirical-psychological investigation was con- ducted by George Northoff; et al, on 5 patients suf- fering with severe PD. All of them showed only mo- tor symptoms. None of them showed any significant change in the *first-person perspective* or their point of view after the implantation of electrode or stem- cell through surgery. However, all patients reported that function of electrode maybe be influenced by their mental and psychological states. The study suggested that patients with brain implants showed no change in their personal identity but, there was a significant transformation in their personality [11].

5. Neuroethics

The term neuroethics was coined by political journalist and *New York Times* columnist William Safire in 2003. He defined it as "A field of philosophy that discusses the rights and wrongs of the treatment of, or, enhancement of the human brain" [8]. This realm addresses the issues that cuts across assorted categories from the impact of neuroscience on sense of self, including and upto, the autonomy given to robots and cyborgs. Walter Glannon from University of Calgary who studies neuroethics is bothered about mind-reading devices or implants that are likely to introduce unprecedented privacy concerns. A vastly unsettling argument in this field is the risks of microchips being hacked by third parties. This could interfere with the user's intention to perform actions and violate privacy by extracting information from chip. Neuroethics has made the provision for exercising the right of cognitive liberty by the patients. However, there is a need for the obligation of neuroethical policies which have neither been defined or delineated in full detail so far. The investigation of some of the overlooked questions such as –

- Do brain implants change and thus manipulate a person in-order to be therapeutically effective?
- Can brain implants enhance or suppress certain traits of the personality?
- Do certain medical and technological therapies change who we are? is indispensable.

6. RESEARCH GAPS

- One of the most vexed research gap is that there is no way of knowing in advance, where to position the electrode sites near neurons of interest.
- Tissue damage is an issue for long-term implants.
- Electrodes are identified as foreign bodies when they are implanted. This results in encapsulation by astrocytes which leads to degradation of recording quality [1].
- Degradation of implant's wire bundle and tether- ing of probes to skull which in turn, results in the perturbation of brain within skull which may cause profound complications such as personality changes.
- The biggest challenge is to make a reliable, long- term connection between hardware and wetware that is unaffected by corrosion, scar tissue, shifting and dying of brain cells.
- Incorrect placement of electrodes and calibration of the stimulator during DBS surgery lead to po- tentially reversible, neuropsychiatric side effects like apathy, hallucinations, hypersexuality, cognitive dysfunction, depression, and euphoria which cannot be considered trivial.

- The ethical conundrums mentioned previously re- main unaddressed since the terms- 'brain', 'person- ality' and 'personal identity' they can be stupefying and cover different domains which require different methodological approaches.

7. PROSPECTIVE APPROACHES FOR RESEARCH

Every scientific advancement has a constant need for innovations and breakthroughs to meet the demands of the ever changing demography that requires medical attention. This stands for brain implants and its variants as well. Following are some of the possible areas which have room for further probes.

- Development of implants that could do both record- ing brain signals and stimulating the brain.
- There is a lot of scope for progress on implants that record signals from motor cortex which could pro- vide front-end for functional neuromuscular stimu- lation.
- Development of electrode arrays that can detect developing seizures and suppress them even before the patient senses them is going to be a colossal landmark in the field of bio-electronics.
- Wireless implants are a feasible solution that is in existence. Nonetheless, Brain-Computer Interface (BCI) needs to be a subject of further innovation.
- Emory University has come up with an ideal fix where an electrode constantly moves to maintain connections. Joel Burdick at Caltech is developing electrode array to do exactly that - embedding electrodes in glass cones filled with nerve-growth factors that encourage brain cells to sprout more dendrites and axons [7].
- Building electrodes out of conducting polymers which are more compatible with neural tissue than silicon/metal would set a new era in the use of technology in medicine.

8. DISCUSSIONS

The advent of brain implants has led to a renaissance in modern neurosurgery and has undoubtedly led to the refinement in the treatment of complex motor problems like Parkinson's Disease, Alzheimer's disease, severe epilepsy and brain seizures. This review has considered a range of therapeutics across journals and the results they have yielded. However, effective control of neu- ropsychiatric complications arising during and after the treatment is the need of the hour. Future challenges in usage of bio-electronics equipment for the management of complex neurological disorders must include an im- proved understanding of the symptoms, unswerving and timely medication, thereby avoiding iatrogenic problems as far as possible. Every practice method must pave way for the patient's neural ethics and his/her 'brain privacy'. Contrivances like memory chip, implant to stream music directly into the brain, implants to control thought process and IQ in humans have to be brought into use only after meticulous evaluation of their pros and cons.

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