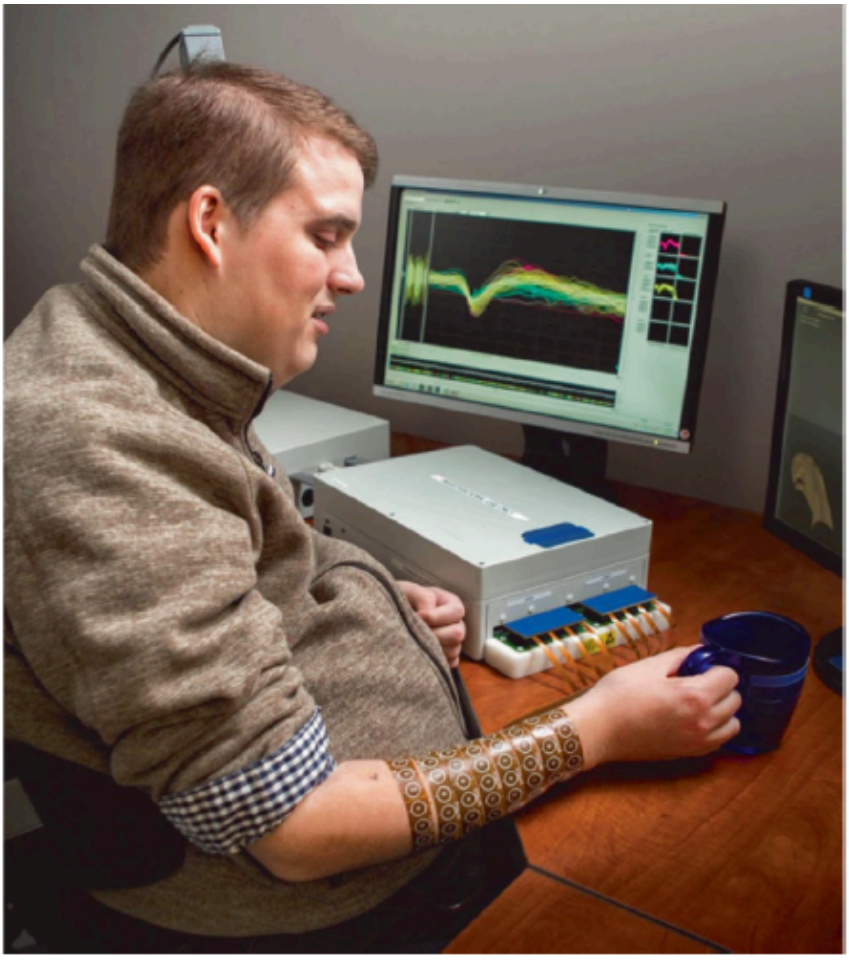
The State of Clinical Trials of Implantable Brain Computer Interface

K. Michelle Patrick-Krueger , Ian Burkhart & Jose L. Contreras-Vidal

Summarized by Bioeng. Aylin Agatha Vazquez Chenlo



Ian Burkhart, one of the authors of this article, had a microelectrode array implanted in 2014 after suffering a traumatic spinal cord injury from a swimming accident in 2010. He is connected to an implantable Brain Computer Interface, which is being used to electrically stimulate his forearm and restore hand function, allowing him to grasp a mug.

(This figure was obtained from the article that is going to be summarized)

P.S. : Thanks to Brendan to make me notice this about Ian Burkhart 😄

Implantable brain-computer interfaces (iBCIs) process intracranially brain electrical activity in order to send instructions to virtual or physical machines capable of restoring or rehabilitating motor, sensory or speech functions in human beings. The article, that I've chosen to summarize, aims to provide an overview of the current perspectives of clinical trials involving long-term iBCIs for communication and sensorimotor control (CSMC) available from 1998 to 2023. Twenty-one research groups are identified worldwide focusing on iBCI that have conducted 28 clinical trials with 67 participants (31 currently active), generating 165 peer-reviewed publications since 1998.

Clinical trials of iBCI for CSMC have been using 4 different types of electrodes:

Electrode	Description	Recovery [1]	Resolution	Duration [2]	Used by	Manufacturer
Neurotrophic electrode (NTE)	Glass cone with electrodes attached where neurites grow	3 months	31 channels in $10mm^2$	Until 13 years	1 research group in 4 patients	Neural signals
Micro-electrode array (MEA)	Array of electrodes in the upper layers of cortex using a pneumatic inserter	Less than a month	Neuronal level; 96 channels in $16mm^2$	3 or 4 years	13 research groups in 38 patients	Blackrock
Electro-corticography (ECoG)	Array of electrodes embedded in a silicone sheet that is placed epidurally or subdurally	-	High; can measure local field potentials	From months up to 9 years	7 research groups in 15 patients	Medtronic, Clinatec and PMT Corp
Endovascular array (EVA)	Endovascular stent inserted via jugular vein and deployed in sagittal sinus, where venous wall tissue grows	Rapid (minimally invasive, no craniotomy)	16 channels in 8 cm	Intended to be a permanent implant	1 research group in 10 patients	Synchron

[1] Recovery after implantation to start experiments. [2] Signal collection longevity after implantation.

There are different functional characteristics of the electrodes mentioned that are critical for the commercial success: longevity, thermal management, mechanical endurance, failure mode and effects, cleanability, protection from electric hazards, and lifecycle management. The authors also remark that some characteristics of components in iBCI are rarely provided and could be very useful to other researchers. In addition to the electrodes mentioned above, there are at least 14 additional electrodes that are currently moving toward in-human long-term trials. Conversely, it is not mentioned deeper information about specific pipelines of signal processing, output device or user interfaces for iBCIs.

The authors allude to different socio-technological aspects of iBCIs. Firstly, they introduce the urgency of creating and adopting standards for performance assessment and benchmarking about terminology, a functional model, data representation, storage and sharing, user needs, sensor technology, and end effectors. Then they mention the importance of tests that include tasks related to daily living activities and how indispensable is data-sharing to advance the technology. In addition, because iBCIs are designed to assist people with substantial impairments, they emphasize the significance of including clinical outcome information and assessments of the psychological effects of using iBCI to assess its risks and benefits for patients, medical providers and regulatory agencies. This article also stands out the development of an intuitive and accessible system designed to address the high turnover of caregivers and facilitate iBCI adoption, including in home settings.

Another aspect they focus is on ethical concerns, particularly the issues of free consent, privacy, agency, and identity that may arise with non-clinical applications after widespread commercialization. Another bother is that BCIs could amplify pre-existing social biases, including limited access in low-resource areas, underrepresentation of women participants and increased stigmatization of patients by emphasizing the social stigma of disability. They point out that identifying these biases and supporting ethical practices aligned with medical objectives, including responsible palliative care, can minimize negative consequences of iBCI adoption.

Moreover, the authors remark business concerns about what long-term obligation do researchers, industry and funding agencies have to participants and about data rights. The main issues are related to patients who wish to keep the implanted device and to whose devices are no longer manufactured or maintained, requiring manufacturers to integrate long-term care responsibilities into their business model or implement healthcare-as-a-service approaches for sustained revenue.

Otherwise, there are other business points about reimbursement and market viability. One of them is about the arduous process of establishing intellectual property, managing regulatory pathways, funding and exit strategies for clinical translation of medical devices. The FDA recognized it, known as the “valley of death”, and introduced a program pilot in 2023. However, numerous neural implants have received regulatory and third-party payer approval, but they failed to remain financially solvent. Especially because of long-term costs, like equipment maintenance and data management, for which little information is available; and for longitudinal costs (mobile apps or robotic prostheses) that may further increase the final cost. There are also associated costs that depend on the quantity and accessibility of the data, which may be subject to retention laws that vary by location and type of facility.

For neurotechnologies, they mention that there is a peculiar barrier: clinical and patient acceptance. Physicians and medical care providers need devices that fit into their workflow, provide tangible benefits over standard treatments, and maintain an acceptable cost-to-risk ratio. Patients, in turn, may be influenced by the general public's skepticism toward neurotechnologies, which could negatively impact both their clinical adoption and iEEGs commercial success.

Finally, they resume the next aspects in the field that need further attention:

- Diversity, equity, inclusiveness and access; because 11 out of 54 participants are women and there is an imbalance age distribution between them.
- Including end-users in product development in order to improve awareness of the challenges when designing this technology.
- Report participant’s data accurately to prevent misinformation (demographic information, electrode details, device longevity and standardized performance metrics).
- The need for training more professionals, including both technical and non-technical.
- Data sharing standardization to develop signal processing and artificial intelligence algorithms to improve the capabilities of iBCIs.
- The urgency to address clinical and translational gaps as well as patient acceptance given that it is expected that iBCIs will enter the medical device market in 2026.

I found this article very interesting regarding the content we have discussed in the course about general concerns about BCI. As a bioengineer, I believe that the majority of what is mentioned above is intricately linked to the present medical advancements, like the controversial semaglutide injections. When it comes to neurotechnologies, I think that the general population is not so used to dealing with them, as their unique approach to medical technologies could be their annual health examination that rarely involves devices like electroencephalograms or any other neurotechnology This could lead to non-real beliefs, more like fictions described, which increases with the current artificial intelligence boom. I am convinced that we, as professionals, must spread science-based information to overcome these obstacles.