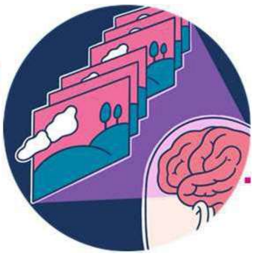

# Development for Clinical Application of Invasive BMI

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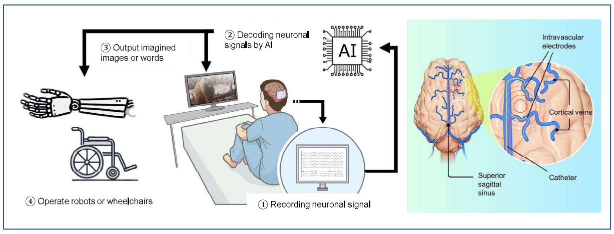
Moonshot Research and Development Program Goal 1 Kanai Project

IoB Core Technology

Overview

We aim to realize a society in which individuals with severe paralysis—such as those with amyotrophic lateral sclerosis (ALS)—can participate socially by controlling cybernetic avatars (CAs) solely through brain activity. To achieve this, we are developing next-generation BMI technologies that enable high-precision measurement of neural signals and accurate decoding of human thoughts and intentions—specifically, 1. We have developed a method for reconstructing imagined images from intracranial EEG signals recorded via electrodes implanted within the skull. 2. We have also established a minimally invasive technique for acquiring high-fidelity intracranial EEG from within the blood vessels, eliminating the need for craniotomy while maintaining high signal precision. 3. Furthermore, we demonstrated that long-term implantation of neural recording devices enables stable measurement of brain activity, thereby allowing BMIs to operate with sustained reliability over extended periods. These advances collectively pave the way for the practical deployment of next-generation BMIs that support autonomous action and communication for individuals with severe motor impairments.




## Development of Brain Information Decoding Technology Using Intracranial Electroencephalograms

We have developed technologies that decode human intentions, recall, and thought content from intracranial EEG (iEEG), and applied them to communication through brain–machine interfaces (BMIs). Notably, we developed a BMI capable of reconstructing the semantic content of imagined images with over 80% accuracy using human iEEG signals (Fig. 1). In this system, we employed the AI model CLIP to represent the meaning of an imagined image as a semantic vector. The system then searched a database of 2.3 million images online and displayed the image whose semantic representation was closest to the decoded vector (Fukuma et al., Communications Biology, 2022; Fukuma et al., under review). Furthermore, using the decoded semantic vectors, we successfully generated both sentences and images (Ikegawa et al., Journal of Neural Engineering, 2024). Additionally, by analyzing long-term intracranial EEG recordings, we identified brain activity associated with spontaneous thoughts experienced in daily life. In particular, we demonstrated for the first time worldwide that sharp-wave ripples (SWRs)—characteristic hippocampal oscillations essential for memory consolidation—are associated with mind-wandering, a form of spontaneous thought (Iwata et al., Nature Communications, 2024; Fig. 2). Together, these findings demonstrate the potential for BMIs capable of decoding and

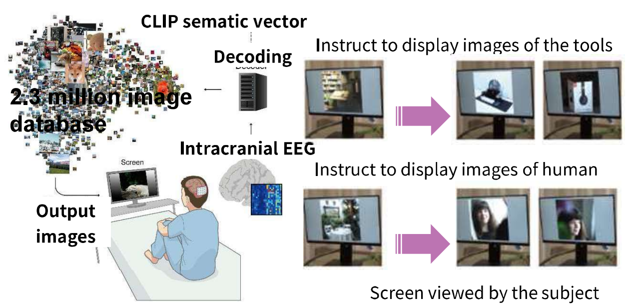



Figure 1. During intracranial EEG recording, participants were instructed to imagine one of two categories of images—either tools or humans—while viewing a screen. From the iEEG signals, the semantic content of the imagined image was decoded, and the system searched a database of 2.3 million images to display the image with the closest semantic representation on the screen every 250 ms. While viewing the output images, participants continued to imagine the instructed category so that the displayed images would match the target meaning. For the two instruction categories, two out of the three participants achieved an accuracy of over 80%.

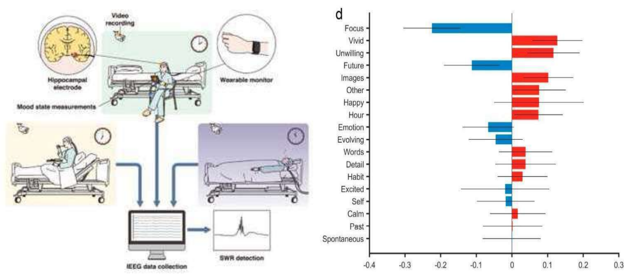



Figure 2. Intracranial EEG and wearable device measures (including activity level and heart rate) were continuously recorded for over 10 days, while participants' thought content was assessed every hour. Sharp-wave ripples (SWRs) were recorded from hippocampal electrodes, and fluctuations in SWR frequency were modeled using mixed-effects analyses with thought content, activity level, and heart rate as explanatory variables. The results showed that variations in SWR frequency were best explained by thought content, with SWRs increasing particularly during periods of mind wandering, when participants were not focused on the current task.

## Development of a BMI Using Intravascular Electroencephalography

In conventional intracranial EEG (iEEG) procedures, electrodes must be implanted through a craniotomy performed under general anesthesia. However, for patients with severe neurological disorders such as ALS, general anesthesia poses substantial risk and physical burden. Thus, there is an urgent need for methods that can obtain high-precision intracranial signals without craniotomy and under local anesthesia. We aim to develop an minimally invasive BMI in which electrodes are delivered intracranially via blood vessels using a catheter, without opening the skull. Traditional intravascular electrodes were rigid, limiting recordings to the superior sagittal sinus that runs along the midline of the cortex, making it difficult to capture signals from broader cortical regions—such as hand and orofacial motor areas—that are crucial for BMI applications. To overcome this limitation, in collaboration with the minimally-invasive group, we developed flexible, ultrathin intravascular EEG electrodes, enabling us to successfully record intracranial signals from cortical surface veins, a feat previously considered technically unattainable. In porcine experiments, electrodes placed in cortical surface veins successfully captured high-resolution evoked responses (SEPs and VEPs), with signal amplitudes exceeding those recorded simultaneously from ECoG. Moreover, stimulation through venous electrodes positioned over the motor cortex elicited muscle responses in the face and forelimb (Iwata et al., Advanced Intelligent Systems, 2025).

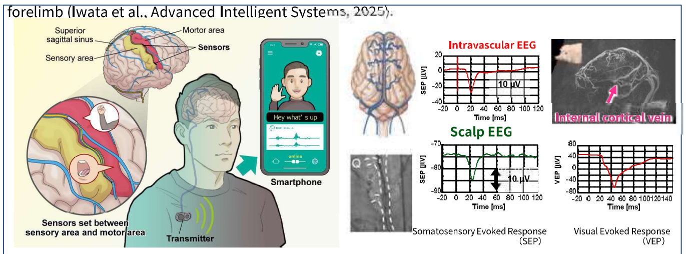



Figure 3. (Left) Conceptual illustration of an ultra-thin intravascular EEG–based BMI. Intracranial EEG is recorded from electrodes placed near the hand and orofacial motor cortices via small cortical veins. The signals are transmitted to an external receiver through a subcutaneously implanted transmitter in the chest. Decoding these signals enables control of a cybernetic avatar (CA). (Right) In experiments using pigs, somatosensory evoked potentials were successfully recorded from cortical surface veins, with amplitudes higher than those obtained simultaneously from ECoG. Furthermore, we successfully recorded intravascular EEG from deep brain regions—where electrode placement via craniotomy is technically challenging—and detected clear visual evoked responses.

## Safety and Efficacy Evaluation of Implantable ECoG Devices

We evaluated the safety and efficacy of an implantable neural recording device that connects to the aforementioned intravascular electrodes and wirelessly transmits brain signals from inside the body. Specifically, a clinically applicable device was implanted in two Japanese macaques, and we demonstrated stable cortical signal recording for more than two years. By conducting motor and sensory tasks over extended periods and training models on the resulting large-scale datasets, we showed that BMIs could be achieved with robust and reliable accuracy. Notably, using deep learning, we found that decoding performance improved according to a logarithmic law with increasing data volume (Fig. 4).

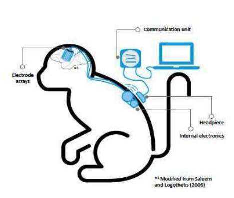



Figure 4. The implantable neural recording device placed inside the monkey's body wirelessly transmits intracranial signals and is powered wirelessly. The decoding accuracy of deep learning models improved according to a logarithmic scaling law with respect to the amount of training data. Using the trained models, we confirmed the successful implementation of BMI control.

## Future Prospects

We aim to translate intravascular EEG-based BMI technology into a medical device and deliver BMI-based communication and cybernetic-avatar (CA) control to patients with severe paralysis, such as those with amyotrophic lateral sclerosis (ALS). In the future, we also envision applying these technologies to support mental and physical well-being, including applications in stress monitoring and autonomic nervous system regulation.

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After completing his M.S. in Science and Engineering at Waseda University in 2000, he transferred to the Faculty of Medicine, School of Medicine, Osaka University, and graduated in 2004. Following initial clinical training in neurosurgery, he developed electrocorticography (ECoG)-based brain–machine interfaces and obtained his Ph.D. in Medicine from the Graduate School of Medicine, Osaka University, in 2009. He was appointed Assistant Professor at the Graduate School of Medicine, Osaka University, in 2012. In 2013, he received the Young Scientists' Prize, a Commendation for Science and Technology, from the Minister of Education, Culture, Sports, Science and Technology (MEXT). In 2016, he became a Lecturer in the Division of Clinical Neuroengineering at the Center for Information and Medical Engineering, Osaka University, and in 2018, he was appointed Professor at the Institute for Advanced Co-Creation Studies, Osaka University. He has held his current position since 2024.

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Internet of Brains