Brain Chip Technology:

Finding a Cure for Paralysis

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On July 3rd 2001, what started as an innocent Massachusetts fireworks show became the crime scene that changed one man's life forever. At 6'2" and 180 pounds, Matthew Nagle was a star football player at Weymouth High. When he was leaving the show, one of Nagle's friends entered into a heated argument. The dispute quickly escalated to blows and Nagle rushed to his friend's aid. During the struggle Nagle was stabbed in the neck by an 8-inch knife that severed his spinal cord. When he awoke in a hospital, he was paralyzed from the neck down. Despite his grim situation, Nagle was determined to find a way to walk again.

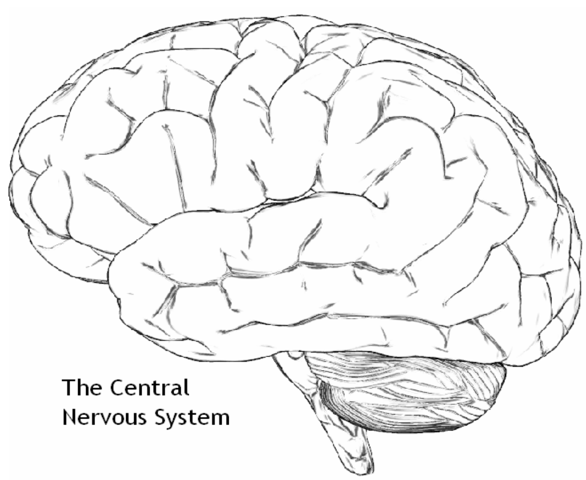
A ray of hope appeared two years later when he read an article in *The Boston Globe* about cutting-edge brain chip research at *Cyberkinetics Inc*. He pleaded with his doctors to contact *Cyberkinetics,* and shortly after he was selected to participate in a clinical trial. In 2004 he became the first person to be implanted with a *Cyberkinetics'* BrainGate® chip.

"I learned to use it in two or three days - it's supposed to take 11 months"
-Matthew Nagle

Young, physically fit and confident, Nagle was the perfect subject."I learned to use it in two or three days - it's supposed to take 11 months," he stated proudly. "I totally knew this was going to work." Three years after his accident Nagle gained the ability to perform basic computer tasks, control a TV, and even operate a prosthetic hand through thought alone. This accomplishment laid the foundation to find a cure for paralysis.

Brain Function

The human brain is the command center of the nervous system. It is composed of 100 billion highly specialized cells called neurons. Through the complex networking of these cells, the brain sends and receives signals that manage biological processes within the body and direct voluntary movement.



In a healthy person, sensory neurons carry signals from the body through the spinal cord to the brain, while motor neurons carry signals from the brain through the spinal cord to all other parts of the body. Nagle's severed spinal cord effectively disconnected his brain from his limbs.

Currently, there are no cures for paralyzed people. However, research concerning the development of brain-computer interfaces (BCIs) presents a potential solution. Successful trials using BCIs in subjects, such as Nagle, provide hope that brain chip technology will one day enable paralyzed people to control computers, wheelchairs, and even their own limbs.

Fifty Years of Progress

Brain chips have been a far-fetched dream ever since Jose Delgado began his research in the early 1950s. Known as the pioneer of brain chip technology, he implanted primitive devices in animal and human brains. Delgado was able to control his subject's emotions by stimulating different areas of the cortex.

In his most famous experiment in 1963, Delgado implanted a miniature electrode, called a stimoceiver, into the brain of a fighting bull. This stimoceiver received and transmitted signals over FM radio waves, and could be controlled remotely. By stimulating a specific part of the charging bull's brain, Delgado was able to stop the bull in its tracks. This and experiments like it, were the earliest forms of BCI research.

In 1998 the first BCI was implanted into a human brain. However, this primitive design had limited functionality. It read neural signals, but produced an impractical output; the person with this chip could "type" only three characters per minute on a virtual keyboard. Three years later, John Donoghue and a group of researchers established *Cyberkinetics: Neurotechnology Systems*, a public company to commercially develop BCIs.

Jose Delgado stimulating the bull

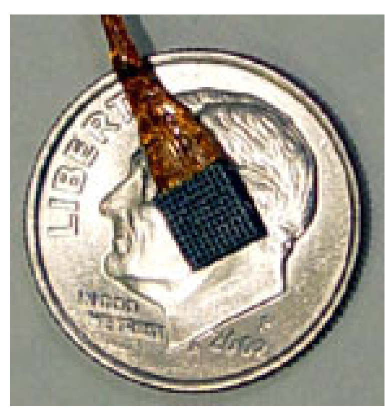
www.wirehog.com

The Chip

Matthew Nagle's brain chip was designed to provide a balance between safety, durability, and functionality. The chip had to be small enough to not hinder normal brain function and non-disruptive to neural communication to avoid brain damage. At the same time, the chip had to be resistant to corrosion caused by brain chemicals. While fulfilling these safety requirements, the primary function of the chip was to record and transmit the delicate signals of Nagle's brain.

Brain chips often fail because of pinholes in their insulation coat. These pinholes allow chemicals and fluid to come in direct contact with the sensitive circuitry of the chip, which results in immediate failure of the chip. Thus the coating material of Nagle's brain chip was of utmost importance. Because of the size constraint, encapsulating the chip in a thick layer of insulation was not a viable option. Instead, the chip implanted in Nagle was coated in monolithic silicone. Its electrodes were coated with Paralyne C, topped with platinum tips and insulated with thin glass. The combination of these materials allowed the chip to be small, durable, and efficient.

Nagle's chip recorded brain signals using integrated CMOS circuitry, which is an array of recording electrodes. Just like repeating an experiment ensures statistically significant results, using multiple electrodes improved the reliability of the recorded data. The



Comparing the Chip to a Dime

[Cyberkinetics Inc]

chip was equipped with 96 recording electrodes spaced 0.4mm apart. It received data at the rate of 10,000 signals per second per electrode. The end size of the chip was 4mm x 4mm x 1.5mm and was implanted a little over 1mm into Nagle's brain.

Implementation

In developing the BCI, researchers implanted a brain chip in subjects with full neural and motor capacity. The subjects performed elementary actions, such as raising an arm, and the neuron activity was recorded using the chip. These experiments allowed for the simultaneous recording of both hand motion and neural activity.

The researchers were then able to create a relational model using the two data sets.

In addition, researchers discovered that although there are multiple sets of neurons that determine the force and direction of motor action, the data from a small sample of neurons can be reconstructed into full three-dimensional arm trajectories using simple multiple linear regression. Researchers found that the placement of the brain chip did not matter as much as originally thought. The chip was able to pick up neural signals not only from the neurons that it directly touched, but also from important nearby neural clusters. This suggests that users of the chip were able to learn how to use the BCI through signals generated by the BCI itself. With prolonged use, the neurons in contact with the chip became increasingly compatible and responsive in performing desired tasks.

Matthew Nagle: Plugged In
www.wired.com

In Nagle's inaugural clinical trial, doctors first pinpointed the exact location in Nagle's primary motor cortex that once controlled his dominant hand. The chip was then implanted at this exact location. After recovering from surgery, doctors thought that it would take 11 months for Nagle to learn how to control a computer cursor using the BrainGate® system. However, Nagle surprised everyone when he began to have success on just his second day of training with the implanted BCI.

The *BrainGate Neural Interface* created a direct link between Nagle's brain and a computer in the following way: when he thought "move cursor down," his cortical neurons fired in a distinctive pattern. The brain chip sensed these electrical signals and transmitted them to a pedestal plug that was directly attached to his skull. The signal was then sent through a wire to an amplifier, where it was converted into optical data and sent to a computer through fiber-optic cables. The BrainGate® system decoded the data associated with Nagle's thoughts into the specified movement of the computer cursor. Thus Nagle was able to play computer games, check email, and draw using BrainGate.

Later in the trial, Nagle developed the ability to open and close a prosthetic hand. All of his accomplishments were exciting not only because of the physical successes, but also because of the manner in which he was able to control the BCI. Like a healthy person, Nagle was able to do other things, such as whistling or talking, while voluntarily "moving" an object, in his case a cursor or a prosthetic hand. In other words, the BCI did not require single-focus concentration.

Furthermore, using the BrainGate® system became intuitive for Nagle. Rather than thinking about the process of moving a cursor by moving his hand, he eventually started moving the cursor by simply imagining the cursor going from place to place. The cursor became as much a part of Nagle as his arms and legs once were.

Researchers removed Nagle's brain chip after one year of observation. Because of the brevity of his trial, it is unknown whether transmitting signals from an implanted chip causes brain damage. Brain experimentation is a risky procedure where minor errors or mechanical malfunctions can lead to permanent damage or even death. Extended research beyond the scope of Nagle's study is necessary to determine the long-term effects of the chip.

A Look Into The Future

Despite all the uncertainties, Nagle's success provides hope and motivation for what researchers envision in the near future of brain chip technology—paralyzed people gaining the ability to fully control prosthetic limbs. Doctors hypothesize that with training and improved technology, the brain can control a prosthetic limb as if it were a part of the body itself. This is supported by research revealing that the adult cortex shows significant functional reorganization after nervous system injuries, changes in sensory experience, or learning of new motor skills.

Bold researchers are even optimistic about the ultimate goal of brain chip technology: to give paralyzed people control of their own limbs. Theoretically, one could bypass the broken motor pathway by hooking up BrainGate® to stimulators that activate muscle tissue. Researchers are currently planning larger clinical trials in order to accomplish this far-off, though seemingly reachable, goal. Donoghue comments, "These are the first steps. The goal is, one day you'd be sitting there with a person who was sipping coffee, typing on a computer, and he'd say, `Oh, by the way, I was a paraplegic but they wired me back together.' The promise is terrific. I think these things will happen. But it will take time."

References and Further Reading

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