Technology Brief 17
Neural Stimulation and Recording

Section 4-12 introduced neural probes and how they can be used to measure voltage at specific locations in the brain. They can also be used to stimulate neurons to control movement, sight, hearing, touch, smell, emotion, and more. Neural stimulation and recording begin with a neural probe such as the three dimensional neural probe shown in **Fig. 4-30** or the spiral-shaped cochlear implant electrodes shown in **Fig. TF17-1**. Each electrode is meant to stimulate one or more nearby neurons.

The electrodes are surgically inserted in proximity to the neurons of interest, and connected onto an electrical stimulation device that sends carefully designed electrical pulses into the extracellular fluid around them (for neural stimulation), or connected to an electrical receiver (that reads signals from them in the case of neural recording). There are many different devices, both commercially available and in research applications, that utilize neural stimulation or recording. These bioelectronics are one of the most exciting and rapidly advancing areas of electrical engineering. Several examples of these devices are given below.

Cochlear Implant

In the ***cochlear implant*** shown in **Fig. TF17-2**, the ear drum and stapes (inner bones of the ear) are replaced by a microphone and electrical circuitry. The sounds are picked up by the microphone mounted behind the ear, processed or coded (using electrical circuitry) into electrical pulses associated with the sounds, and then transmitted through the skin via inductive coupling or direct connection to the electrodes. The electrodes place these signals directly onto the auditory nerves, which then send the signals to the brain, which "hears" the sound. If the auditory nerve is not functional, an ***auditory brainstem implant*** is used instead, wherein electrodes directly stimulate the cochlear nucleus complex in the lower brain stem.

Artificial Eye Retina

The ***artificial retina***, or ***cortical implant***, replaces damaged eye structures with an external camera, a wireless link (shown as the two orange inductive coils in **Fig. TF17-3**), and an electrode array that stimulates the optic nerve in the back of the eye. Another alternative is to bypass the optical nerve and stimulate the visual cortex of the brain directly. The resolution of sight depends on the number of electrodes, as shown in **Fig. TF17-4**.

Brain Stimulation

The ***deep brain stimulation*** (DBS) or ***cognitive prosthesis*** shown in **Fig. TF17-5** is used to stimulate

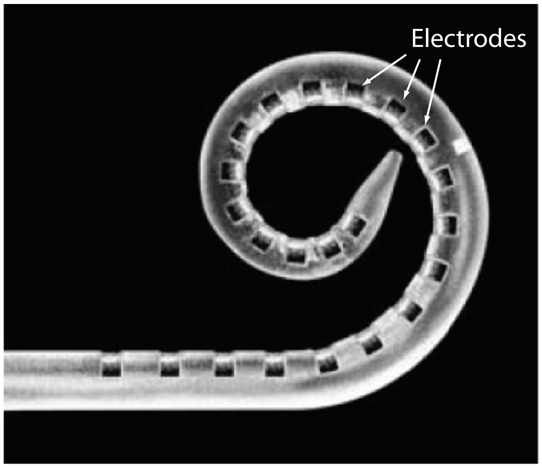

Figure TF17-1: Preformed spiral electrode for cochlear implant. (Courtesy of Cochlear Americas, © 2015 Cochlear Americas.)

1. Sounds are picked up by the microphone.
2. The signal is then "coded" (turned into a special pattern of electrical pulses).
3. These pulses are sent to the coil and are then transmitted across the skin to the implant.
4. The implant sends a pattern of electrical pulses to the electrodes in the cochlea.
5. The auditory nerve picks up these electrical pulses and sends them to the brain. The brain recognizes these signals as sound.

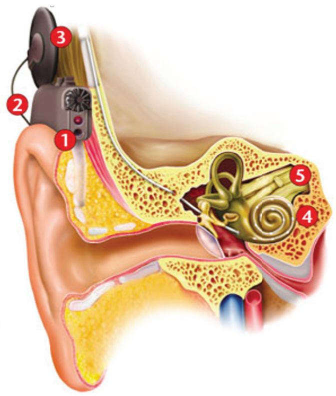

Figure TF17-2: A cochlear implant stimulates the auditory nerves to help deaf people hear. (Courtesy MED-EL.)

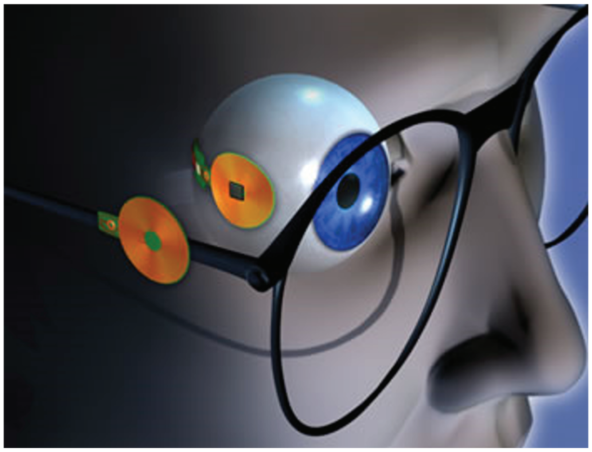

Figure TF17-3: Artificial retina simulates the optic nerve to help blind people see. (Credit: John Wyatt.)

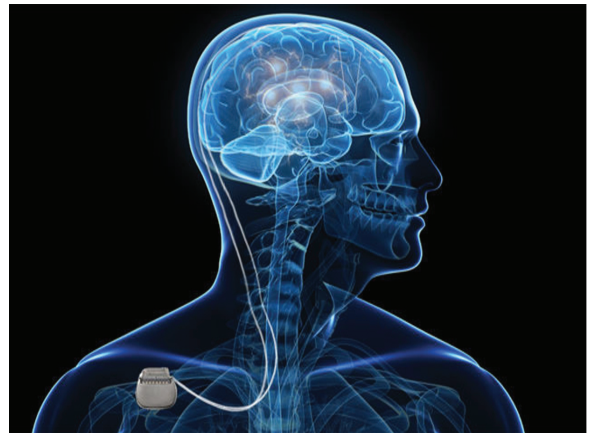

Figure TF17-5: Deep brain stimulation (DBS) is used to treat depression and tremors associated with Parkinson's disease. (Credit: Medtronic.)

nerves deep within the brain. This has been used to reduce tremors due to Parkinson's disease and to relieve some types of depression, and it has been proposed for treating a number of other psychological and physiological disorders. The development of applications for direct stimulation of the brain is often preceded by neural recording, to help researchers better understand the natural electrical signals in the body.

Sensory and Motor Prostheses

Several designs of ***sensory/motor prostheses*** are being developed to help patients with spinal cord injuries, damaged or amputated limbs, loss of bladder control, and other physical impairments. If only the nerve connections are damaged, these may be replaced by neural recording (to receive signals) and stimulation devices (to transmit them), thus returning some level of motion control. If a limb is entirely gone, it can be replaced by an artificial limb, controlled by neural recording and stimulation (**Fig. TF17-6**). An interesting phenomenon associated with these and many other types of neural prosthetics is that the plasticity of the brain often allows the user to learn and train the brain and body to see, hear, touch, and move based on the adapted machine-brain interface from the neural signals.

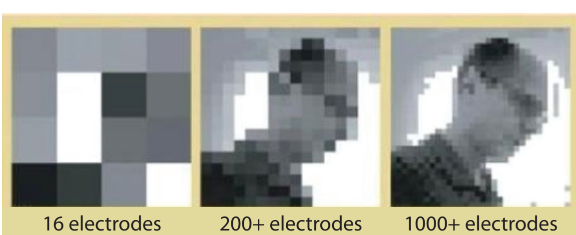

Figure TF17-4: Vision resolution expected with various numbers of sight-stimulating electrodes.

Pain Control

Another application of both internal and external electrical stimulation is in control of pain. Basically, the pain signals are masked by a stimulation-induced tingling known as ***paresthesia***. Internal devices used to induce paresthesia include the ***spinal cord stimulator*** (SCS) shown in **Fig. TF17-7** and external devices include ***pulsed electromagnetic field*** (PEMF) stimulators. External devices use one of two methods for directing the pulsed energy to the location of the pain. One method involves inductive coupling (using coils external to the body), and the other involves the use of two electrodes on either side of the region, transmitting current from one electrode through the body region to the other electrode (**Fig. TF17-8**). PEMF devices have also been used to improve bone and soft tissue healing.

Emerging technology in neural prostheses and other body-machine interfaces has already provided life improvements for many. This technology is still in its infancy,

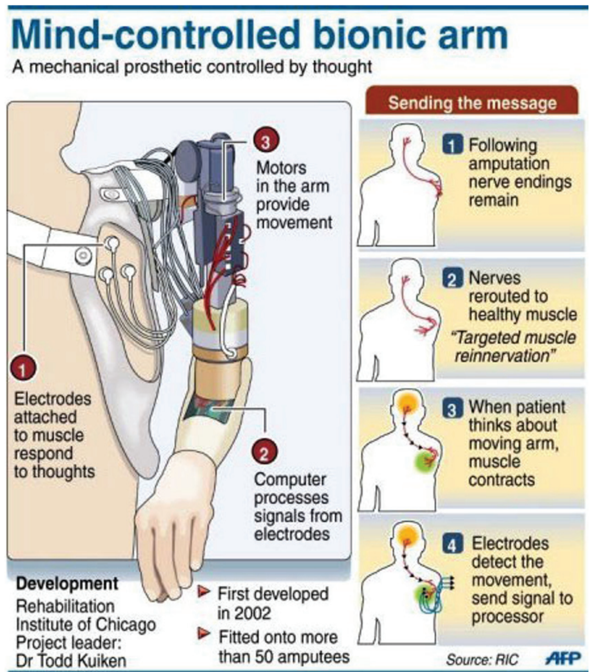

Figure TF17-6: Mind-controlled bionic arm uses both neural recording and neural stimulation within the brain and at the attachment site of the artificial limb. (Credit: Todd Kuiken, MD, Center for Bionic Medicine.)

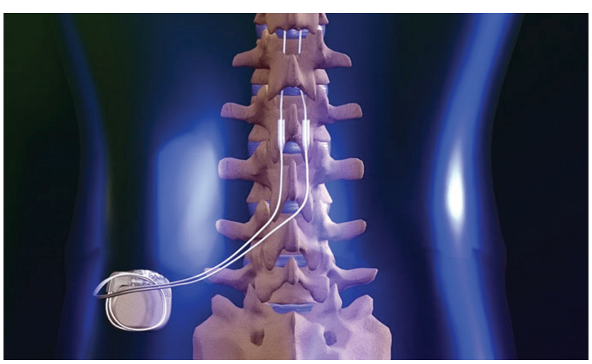

Figure TF17-7: Spinal cord stimulator (SCS). (Credit: Spine-health.com.)

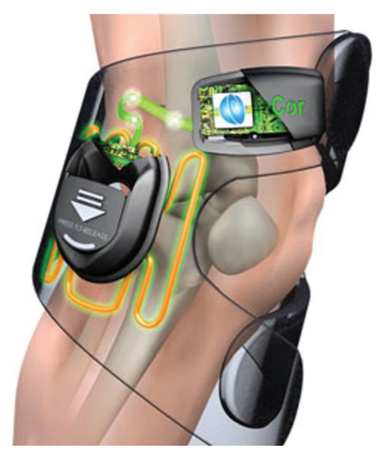

Figure TF17-8: Wearable pulsed electromagnetic field (PEMF) pain-control device for the knee. (Credit: Orthomedical.)

and many interesting challenges remain. How to create a full-function, long-term biocompatible implant small enough to be placed directly into the eye, brain, spine, bladder, brain and other organs, with battery life and/or power harvesting to support its operation, but with heat and power low enough not to damage the critical neurons it is connected to, surgically placing it correctly every time for every patient, with easy ways to get information to and from the device … there are enough challenges to keep engineers engaged for decades to come!