Restoring Sight to the Blind

MILLIONS of people worldwide suffer from ocular diseases that degrade the retina, the light-processing component of the eye. As the population continues to age, the number of Americans blinded by age-related macular degeneration and inherited retinal disorders such as retinitis pigmentosa will increase. A retinal prosthesis can be used to treat blindness caused by these diseases. However, no company in the world has obtained regulatory approval to market a retinal prosthesis.

In collaboration with four other national laboratories, four universities, and one industrial partner, Livermore scientists have developed the first long-term retinal prosthesis that can function for years inside the harsh biological environment of the eye. The device, called an artificial retina, uses application-specific integrated circuits for transforming digital images from a camera into electric signals in the eye that the brain can use to create a visual image.

In 2004, the team was established through a Cooperative Research and Development Agreement with the mission of developing the world's most advanced high-density microelectronic–tissue prosthesis for imaging. This year, the team won an R&D 100 Award for the second-generation technology. In clinical trials of patients with vision loss, the patients successfully identified objects, increased their mobility, and detected movement using the artificial retina. Livermore team leader Satinderpall Pannu says, "The artificial retina has become the state of the art in visual prostheses and will enable blind individuals to accomplish things they have not dreamt were possible."

System Specs at a Glance

Patients afflicted with retinitis pigmentosa or age-related macular degeneration lose their ability to perceive light when the disease destroys the retinal photoreceptor layer. To restore sight in these patients, the artificial retina system converts images from a digital camera into controlled electrical impulses that stimulate the remaining bipolar and ganglion cells. The brain perceives patterns of light spots corresponding to the stimulated electrodes.

The artificial retina system includes a tiny video camera and transmitter mounted in sunglasses, with a small visual processing unit and battery pack worn on a belt. The camera captures an image and sends it to the visual processing unit, which converts the image to an electronic signal and sends it to the transmitter. The retinal implant receives this signal via wireless transmission and encodes it into specific patterns of stimulation pulses, which are conducted through a tiny flexible cable to an electrode array. These pulses stimulate the retina and enable the brain to perceive patterns of light.

The artificial retina development team at Livermore: (from left) Erika Fong, Emil Geiger, Satinderpall Pannu, Maxim Shusteff, Kedar Shah, Terri Delima, Julie Hamilton, and William Benett. (Not pictured: J. Courtney Davidson and Phillipe Tabada.)

Seeing Results

In ongoing clinical trials, human subjects using the artificial retina successfully identified the position and approximate size of objects, and detected movement of nearby objects and people. Objects were recognized within 2 to 3 seconds, and the device's

with an Artificial Retina

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second-generation 60-electrode prosthesis showed improved image resolution over the first-generation 16-electrode prosthesis.

The prosthesis is now of sufficient resolution to allow recognition of doors, windows, edges, low-lying branches, and the square on a basketball backboard. Preclinical testing is under way of an implant with more than 200 electrodes, which will further improve a patient's mobility and object recognition. Additional research and development will produce artificial retinas with more than 1,000 electrodes, which potentially will allow patients to recognize faces and read.

The team's artificial retina is the only retinal stimulator in large-scale, long-term clinical trials. The device has a fully portable external system, and the implant can withstand daily use for many years. Patients in clinical trials have used the artificial retina system outside clinical settings—both at home and in public. In contrast, all competing retinal stimulators have been used for only short-term research that restricted subjects to a clinical setting. In addition, competing retinal stimulators use polymers to protect their microelectronics, resulting in implants that will function for just weeks to months if used daily. The artificial retina, however, with its metal–ceramic biocompatible electronics package is designed to last more than five years with daily use.

"Our implantable technology allows microelectronics to be placed safely within the eye without damaging the biological tissue," says Pannu. "The microelectronic system can send and receive information, opening the window to a number of therapeutic and diagnostic modalities. Eventually, a nanoelectronic system will be possible."

Foresight

Technology used in the artificial retina could conceivably be adapted to help patients with spinal-cord injuries, Parkinson's disease, deafness, and many other neurological disorders. For example, the technology may be adapted for existing cochlear implant systems to improve hearing, for spinal-cord stimulators to treat pain, for deep-brain stimulators to help control tremors, and for sensors to control prosthetic limbs or mobility aids. The same microelectronic system may also be modified to interface with other cell types such as plants and bacteria, which means it could ultimately be used for a variety of different applications including environmental cleanup and countering bioterrorism. "This strategy may be adapted for many applications," says Pannu. "We have just begun to look at the tip of the iceberg."

—Kristen Light

Key Words: age-related macular degeneration, artificial retina, blindness, ocular disease, R&D 100 Award, retinal implant, retinal degeneration, retinitis pigmentosa.

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