A Second Chance at Sight

A retinal prosthetic device with a 240-electrode array is biocompatible, conforms to retinal tissue, and is mechanically robust.

LIVERMORE is bringing its expertise in micro- and nanomaterials development and systems integration to a Department of Energy (DOE) project that is creating a new artificial retina. Six national laboratories, three universities, and private industry are combining their resources to create a retinal prosthetic device to restore sight to the blind.

To implant DOE's retinal prosthesis, doctors thread an electrode-studded array through an incision in the eye and attach it to retinal tissue. In 2002, the first such operation was performed on a 77-year-old patient who had been blind for 50 years. Within weeks, he could see patterns of light and dark that allowed him to detect motion and locate and differentiate simple objects. Since then, five more volunteers have had the 16-electrode device inserted in an eye.

This spring, a patient received the first prosthesis with a 60-electrode array. An even newer laboratory version contains more than 200 electrodes, yet it is thinner and conforms better to the shape of an eye than earlier models. Work is also under way on a prosthesis with over 1,000 electrodes. As shown in the figure on p. 21, at least 1,000 electrodes are needed for a person to be able to recognize faces.

Vision loss because of retinal disease affects about 6 million Americans and 25 million people worldwide. Retinitis pigmentosa and age-related macular degeneration are the primary causes of retinal disease. Both ailments destroy the light-sensing cells (photoreceptors) in the retina, a multilayered membrane located at the back of the eye. These cells do a poor job of repairing themselves. Because no effective treatments exist, those blinded by the diseases must accept their condition and adapt to life in a sightless world. Blindness takes a toll not only on the blind individuals and their families but also on national economies, adding to health-care spending burdens because patients often require significant aid. An additional spur for finding a solution to retinal disease is our aging population. The number of those affected by retinal disease will continue to grow and, according to some estimates, may even triple by 2025, creating an epidemic of vision loss.

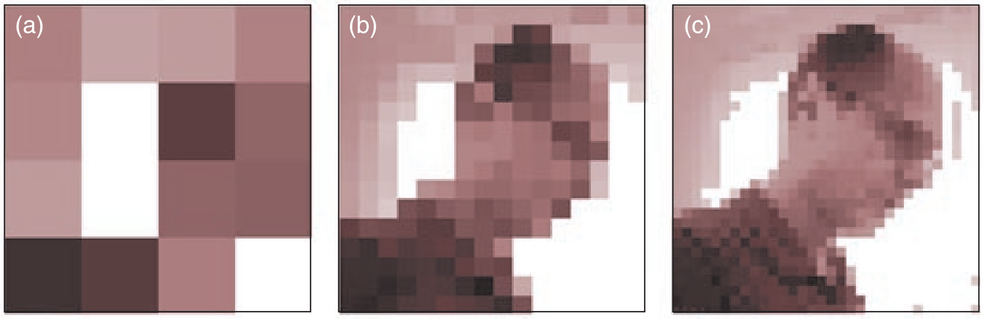
The Doheny Eye Institute at the University of Southern California is leading DOE's Artificial Retina Project. Mark Humayan, a retinal surgeon and biomedical engineer at Doheny, is the principal investigator of the project. Before working at Doheny, Humayan was at Johns Hopkins University. In the early 1990s, a team he led discovered that patients with retinal disease could still receive light signals through electrical stimulation of the remaining neural wiring in the retina. Work then began on an implantable microelectrode array that could communicate with the remaining functional cells and stimulate visual perceptions. In 2005, *R&D Magazine* named Humayan as Innovator of the Year.

DOE established its Artificial Retina Project in 1999, and Livermore has been involved from the beginning. (See *S&TR*, November 2003, pp. 11–13.) Other participants include Second Sight Medical Products, Inc.; Argonne, Brookhaven, Los Alamos, Oak Ridge, and Sandia national laboratories; North Carolina State University; and the University of California at Santa Cruz. Second Sight created the first 16-electrode models. It will also be responsible for clinical trials and eventual commercial distribution of the retinal prosthesis to patients.

Inside the Delicate Eye

The technologies that produced the heart pacemaker and the cochlear implant to aid the deaf formed the foundation for the development of the retinal prosthesis. Because the artificial retina must function in the eye, a very delicate environment that is constantly bathed by bodily fluids, advanced technologies are needed.

The prosthesis consists of a tiny camera and microprocessor mounted in eyeglasses, a receiver implanted behind the ear, and an



These images approximate what patients with a retinal prosthesis see with (a) 16 electrodes, (b) 256 electrodes, and (c) 1,000+ electrodes. (Images generated by the Artificial Retinal Implant Vision Simulator devised and developed by Wolfgang Fink at the Visual and Autonomous Exploration Systems Research Laboratory, California Institute of Technology.)

electrode-studded array attached to the retina. The camera captures an image and sends the information to the microprocessor, which converts the data to electronic signals. These signals are then transmitted to the receiver. The receiver sends the signals to the electrode array, stimulating it to emit electrical pulses. The pulses travel through the optic nerve to the brain, which perceives patterns of light and dark spots corresponding to the electrodes stimulated. Patients learn to interpret the visual patterns produced.

At the heart of the artificial retina is the electrode array, which was designed, fabricated, and initially tested at Livermore. The first designs for the electrode array used a silicone-based substrate, which the Laboratory had successfully applied to other biocompatible devices. "However, silicone is stretchy," says Satinderpall Pannu, who leads the Livermore team, "and the metal electrodes attached to the substrate tended to break." In the latest designs, the electrodes are mounted on a proprietary substrate material developed by Second Sight.

To fit in a patient's eye, the array can be no larger than 5 millimeters wide. The electrodes must be very small yet large enough to receive sufficient energy for stimulation. Because of these space constraints, a retinal prosthesis containing more than 1,000 electrodes will require the development of new electrode materials.

The electrode array also incorporates the electronics that allow communication between the receiver behind the ear and the electrodes in the eye. Sandia is responsible for the electronics, while Livermore is designing the package that contains them. Livermore is also responsible for the interconnects between the electronics and the electrode array. Earlier designs of the prosthesis used a tiny cable between the receiver and the electronics on the array. Communications are now wireless.

The electrode array is embedded in a high-density polymer thin film. Livermore experts in nano- and microelectromechanical systems design created the tiny electrodes and methods for attaching them to the substrate. Livermore's expertise in the design and fabrication of novel materials was thoroughly tested in this project. "Improving the adhesion forces between layers of polymers and metals was a challenge," says Pannu.

On the array, the electronics package and electrodes are mounted at opposite ends. The package must be biocompatible, and no gas can be exchanged between any of the materials and the eye. Pannu calls this work "a very challenging part of the project" for the team.

At Doheny Eye Institute, the prostheses are tested on dogs to ensure all materials are biocompatible and fully functional in the eye. For example, water from the eye may cause a short circuit in the device. For these tests, a prototype prosthesis is inserted in one eye of a blind dog. After 6 months in the dog's eye, the prosthesis is removed and tested by Doheny and Second Sight. Testing of the electronics package reveals whether the case is hermetically sealed.

Surgical Updates

More effective prostheses are becoming available, and patients who received the earlier models may want an update. However, because the 16-electrode array is attached directly to the retina, it cannot be removed. Pannu's team is now developing a new surgical tool and technique that will allow electrode arrays to be replaced as newer versions become available.

The Council on Competitiveness, a nonprofit, nonpartisan policy action group that sets an action agenda to drive U.S. competitiveness and economic leadership, featured DOE's Artificial Retina Project at its 20th anniversary celebration in November 2006. The council considers the ability to restore lost sight a premier example of this country's competitive edge. Restoring sight is also the right thing to do.

—*Katie Walter*

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For more information on DOE's Artificial Retina Project, see http://artificialretina.energy.gov.