Artificial limbs wired direct to the brain

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Enlarge image

Former US marine Claudia Mitchell became the first woman to be given a "thought-controlled" bionic arm (Image: Win McNamee/Getty)

The prospect of being able to replace damaged limbs with prosthetics that plug straight into the nervous system is moving from fantasy to reality. In July researchers at Brown University in Providence, Rhode Island, revealed that electrodes implanted in the brain of Matt Nagle, who is paralysed from the neck down, allowed him to control a robotic arm and even play computer games.

One of the key components of truly bionic body parts, which can be controlled by the brain, is the connection that enables communication between the prosthesis and the nervous system. Implanted electrodes are needed to pick up signals from the brain or to stimulate nerves to feed sensory information back to it, and until now these electrodes have been rather crude. They are so large that rather than connecting to just one nerve or brain cell, each one connects to dozens if not hundreds of cells. This makes it difficult for an electrode to tune into its target signal without receiving or creating interference with neighbouring cells. It's a bit like trying to follow a single conversation when surrounded by people at a noisy party.

Adding to the problem is the fact that implanted electrodes don't always stay where the surgeon puts them. For example, an electrode for a prosthetic forearm implanted in a vestigial limb can be jolted away from its target neuron by sudden body movements. In a similar way, brain implants can be steadily pushed out of place by the growth of fibrous tissue around them. So even when the neurosurgeon does manage to tap into a strong signal, the connection may only last a few months, says Richard Andersen, a neuroscientist at the California Institute of Technology in Pasadena.

"When implanting patients you really want to have an optimal signal from many electrodes that can record indefinitely," Andersen says. To try and achieve that, he is working with Joel Burdick at Caltech to develop brain implants for paralysed people that can sense where the strongest neuronal signal is coming from and move towards it, ensuring that once an electrode is plugged into a signal it stays plugged in. This is vital when implanting electrodes into people's brains, says Andersen, as each surgical procedure brings with it a risk of infection and brain damage, so repeat operations are something to be avoided if at all possible.

The team's first attempt involved an implant attached to the skull that used piezoelectric motors connected to an array of electrodes. The piezoelectric crystals expand in response to an applied voltage, moving individual electrodes up and down (*New Scientist*, 13 November 2004, p 25). Tests on animals showed that the electrodes can actively seek out the strongest signal. The electrode first moves in a direction chosen at random, then reads the signal to detect if it has become stronger. If so, it makes another small movement in the same direction; if not, it retraces its steps and tries another direction.

The device proved far from perfect, however. It is quite energy-hungry, and it measures 3 millimetres across and 22 millimetres long, making it too large and impractical to implant into someone's brain indefinitely. Now Andersen and his team have got together with Yu-Chong Tai, a researcher in microelectromechanical systems (MEMS), also at Caltech, to develop a more compact device.

The new implant uses pneumatic actuators to position its electrodes. Oxygen and hydrogen generated by passing an electric current through water in an enclosed chamber expand a diaphragm, which pushes on its surroundings, causing the electrode to move. To reverse the movement, the gases are recombined to turn them back into water.

In the prototype the gases press on a thin, flat silicon diaphragm, deflecting it slightly so that it presses against the electrode. In the final version, Andersen says, the actuators will be more like bellows in which the water will be held in inflatable balloons 1 millimetre in diameter. These will expand as the water is converted into gases, pushing the electrode out of its silicon housing. The entire device will be just 1 millimetre wide and will be capable of moving the electrodes as far as half a millimetre.

Andersen points to the significant advantages of this set-up compared with traditional actuators. "Piezoelectric actuators require high voltages, while motors need constant power and generate heat," he says. The pneumatic device, by contrast, will use much less electrical energy, which the team hopes can ultimately be supplied wirelessly via a small loop antenna. To ensure that it does not damage brain cells, the device will also be able to detect if the signal strength is increasing too quickly, indicating it is likely to collide with the neuron, and will back off.

Also investigating the use of mobile electrodes to control bionic limbs are researchers taking part in the Cyberhand Project. This pan-European programme, led by Paul Dario at the Sant' Anna School of Advanced Studies in Pisa, Italy, is aiming to fit two amputees with fully functional prosthetic forearms by this time next year. The artificial hands, which will be controlled by electrodes implanted in the upper arm, will also relay touch sensations from fingers to provide better control when handling objects.

"An artificial hand, controlled by electrodes in the upper arm, will relay touch sensations"

To ensure the implant transmits and receives the strongest and most consistent signals to control the hand or respond to its movements, Klaus-Peter Koch at the Fraunhofer Institute for Biomedical Engineering in St Ingbert, Germany, has been developing an implant that can home in on nerve cells. Made of slivers of shape memory alloy 6 centimetres long but only 10 micrometres thick, the electrodes deform at various points along their length when heated by an electric current applied to that part of the electrode. This allows them to bend out from their substrate and push up against their target nerves. Each electrode has eight electrical contact points, which connect with different nerves. By snuggling up to their target nerve in this way, the electrodes are better able to pick out the target signal from the noise of surrounding cells.

Research into the moving electrodes is still at an early stage, so the devices will not be ready for use in prototype Cyberhands that are due to be tested by volunteers in the coming year. The team is planning tests on animals soon, and preliminary experiments in the laboratory have shown the electrodes work well, and that the heat they produce is not so intense that it damages surrounding tissue.

Koch says efficient electrodes play a crucial role in allowing prosthetics to be used to replace damaged limbs, and that the moving electrodes will bring about a big improvement. In the past, surgeons implanting electrodes wouldn't know their exact position, and this made it difficult to be sure they would work effectively, he says. "Now even if they move a few tens of microns we can move them back."

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More lifelike sound from cochlear implants

Cochlear implants overcome deafness by bypassing the ear itself and directly stimulating the auditory nerve. For this to be effective, the positioning of the electrodes is crucial, and initially this was a hit and miss affair. Surgeons had to wait for the patient to recover from the operation and then simply ask them if they could hear anything when each of the electrodes was activated.

More recently, audiologists have routinely tested implants during surgery by stimulating the nerve with each electrode and then reading the signal produced by the nerve. The disadvantage of this more objective approach is that it tends to add around 30 minutes to the procedure, increasing the risk of complications.

Now the Australian company Cochlear, based in Lane Cove, New South Wales, has developed an automated system that can complete the test in 10 minutes. Each electrode is stimulated in turn, while neighbouring electrodes are used to automatically record at what level it has an effect on the nerves. The procedure can be carried out without a trained audiologist having to be present, says Bas van Dijk, an audiologist with the company. He says trials of 29 patients have also shown the self-tuning implant produces more consistent results than manual tests.

Now the company has set its sights on a more dramatic improvement to the device's sound quality. One limiting factor is the number of electrodes placed along the nerve. Normally no more than 22 can be squeezed in because there is not enough space within the ear for the wires needed to connect each electrode to the control device.

To increase the number of electrodes without increasing the number of wires, the company is using multiplexing, a technique used by the telecommunications industry to send separate signals down a single wire by transmitting them via carrier waves of different frequencies, just as radio programmes can be carried on different frequencies. Each point on the nerve represents a different band of audio frequencies that the patient will hear, so a cochlear implant that stimulated nerves in 100 or more different places instead of 22 would dramatically improve the quality of people's hearing, van Dijk says.