



FANCY FINGERWORK
Jason Koger practices picking up small rock-type pieces during a therapy session at Hand Therapy, in Owensboro, KY.

The Six Million Dollar Arm

A new surgical procedure enables people to move a prosthetic limb—with their thoughts.

BY DEBRA GORDON

It was a perfect late spring day, the kind meant for feeling the sun on your back and the wind in your face. But Claudia Mitchell, a marketing student at the University of Arkansas, had homework to do. So when her friend Nick invited her for a ride on his new motorcycle on that May afternoon in 2004, she initially said no. He upped the ante with an offer of barbecue and Claudia finally agreed. She changed out of her shorts and tank top into jeans, a long-sleeved shirt, and the military combat boots she kept from her four years in the Marines. No way was she getting on a motorcycle without protective gear! When Nick turned up with only one helmet, she refused to go without one. He insisted she wear his.

"I remember telling him that I thought he was crazy for riding without one," she says. She also thought he was driving

too fast but figured he'd slow down on the curves. He didn't. Nick lost control of the bike, and they both went flying. He hit the pavement first; Claudia hit the guardrail and landed on the other side. She didn't realize how badly she was hurt until she tried to push herself up with her left arm.

"My arm isn't working!" she cried out. The reality was that her arm was gone, severed at the shoulder by the guardrail.

Although rescue workers found the arm, immediately put it on ice, and brought it to the hospital with Claudia, the damage was too great. It couldn't be reattached. Just 23 years old and five months out of the Marines, Claudia steeled herself to live without her left arm.

Today, she can fold clothes standing up. Peel a banana. Open a peanut butter jar. Hold a bowl still while mixing its contents with

PHOTO BY JENNY SEVCIK/ MESSENGER-INQUIRYER/ AP PHOTO

“Even though you’ve lost an arm, **the information** you need to operate a robotic arm is still there in the leftover nerves,” Dr. Kuiken says.

her other arm. All by just thinking about it. She owes her “bionic” arm to more than two decades of work by physician and engineer Todd Kuiken, M.D., Ph.D., director of the Neural Engineering Center for Artificial Limbs (NECAL) at the Rehabilitation Institute of Chicago. Dr. Kuiken turned the previously unthinkable into reality: a prosthesis that moves in response to thought.

MOVEMENT WITH THE MIND

Todd Kuiken was a graduate student in engineering simultaneously completing medical school and looking for a thesis topic when he stumbled upon what would become his life’s work. As he read through dozens of journal articles about amputation and prosthetics, his area of interest, he spotted it: one line in the discussion section of a paper on prosthetics. “It said maybe nerves could be transplanted to muscles to get different signals,” he recalls.

Today there is no “maybe” about it. Targeted muscle reinnervation (TMR) is a reality, enabling people who lost an arm to manipulate an advanced prosthesis simply by thinking about it.

“The idea is that even though you’ve lost an arm, the information you need to operate a robotic arm is still there in the leftover nerves,” Dr. Kuiken explains. Think of your spinal cord as a telecommunications cable, only instead of wires it is filled with thousands of motor and sensory nerves. Some of those nerves branch out from the spinal column to “innervate”—that is, provide sensation and messaging—to arms, legs, and other parts of your body, much like the wires in that cable branch out your house.

Unless those wires connect to a phone or computer, however, they’re worthless. Same thing with nerves: If they don’t connect with muscle, they can’t fulfill their communication role. Amputate an arm or leg and it’s as if you cut the wire leading to your computer. Unlike wires, nerves continue to grow; but without muscle to innervate, they form a bundle called a neuroma that often causes excruciating pain in amputees.

What Dr. Kuiken and surgeon Greg Dumanian, M.D., did was figure out a way to regrow the nerves into muscle so they could once again do their job. But instead of transmitting message to the flesh and blood, they would transmit the signals to sensors in a prosthesis.

Dr. Dumanian, an associate professor of plastic surgery at Northwestern University’s Feinberg School of Medicine, recalls the first time Dr. Kuiken talked with him about the possibility of reinnervation for amputees. “He didn’t realize [nerve transfer] was already part of clinical medicine,” Dr. Dumanian says. The technique had been used for many reconstructive procedures, including brachial plexus surgery, in which the network of nerves that control movement and sensation in the shoulder, arm, and hand are repaired. “I said, ‘That’s easy. I could do that tomorrow.’”

Targeted muscle reinnervation involves removing healthy nerves from the chest or other muscles, cutting off the neuroma from the nerves that originally fed the missing limb (in order to stimulate the nerves to grow again), and then attaching the nerves that originally fed the missing limb to the chest muscle and skin. After about six months, the nerves “arborize,” or grow into the muscle, becoming fully functional.

“The muscle acts as a biological amplifier,” explains Dr. Kuiken. Once the nerves have regrown, simply thinking about bending your elbow transmits the message to those nerves, which send out an electrical signal picked up by electrodes on the muscle and transmitted to the prosthetic arm. Voila! A bent elbow with none of the physical gyrations typically required to move a prosthesis.

Currently, the procedure has only been done with the nerves responsible for opening and closing the hand and bending the arm up and down. Dr. Kuiken and his team are now using computer algorithms (called “pattern-recognition”) to decode neural signals required to move fingers and wrists. Hopefully this will allow for even more natural movement.

“Rather than just opening and closing the hand, the patient can think, ‘I want to be in a pinch grip with my thumb and forefinger’ and the hand will operate in that way; or the patient can think, ‘I want to be in a power grip to hold a baseball bat’ and

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For More Information

Targeted muscle reinnervation (TMR) has moved past the experimental phase and is now available for patients outside of a research study. Dr. Kuiken and his team are available to help train other healthcare professionals so they can offer the procedure and prosthesis to their patients. For more information, contact the Rehabilitation Institute of Chicago at ric.org, or call 1-800-354-7342. Patients may also contact Dr. Dumanian through his Web site, northwesternplasticsurgeons.com.

If you’d like to read what the experts read, get out your medical dictionaries and check out these journal articles:

- ▶ Kuiken TA, Li G, Lock BA, et al. “Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms.” *JAMA*. 2009;301(6):619-628.
- ▶ Marasco PD, Schultz AE, Kuiken TA. “Sensory capacity of reinnervated skin after redirection of amputated upper limb nerves to the chest.” *Brain*. 2009.

**BACK IN DADDY'S
ARMS AGAIN**
Koger with daughters
Cambell, left, and
Billie, at their home
in Utica, KY. Koger
became a double
amputee after
being shocked by
live electric wires in
March 2008.



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the hand will operate that way,” Dr. Kuiken says.

So far, only about 40 people around the world have had the reinnervation surgery. The best candidates for targeted reinnervation, says Dr. Kuiken, are people with above-elbow and shoulder level amputations who are motivated to wear a prosthesis. Those who have experienced damage to the brachial plexus—the network of nerves that sends signals from the spine to the shoulder, arm, and hand—or whose chest or arm muscles are paralyzed on the side of the amputation are not good candidates for the procedure.

The first surgeon outside Chicago to begin doing the procedure was orthopedic and trauma surgeon Douglas Smith, M.D., at the University of Washington’s Harborview Medical Center in Seattle. He’s begun reattaching the nerves in trauma patients during the same procedure in which the limb is amputated. This allows him to avoid another surgery and prevent the development of painful neuromas. At least half of amputees experience the “phantom pain” caused by these neuromas, real pain that feels as if it emanates from the missing limb. Studies find that this pain significantly and negatively affects their overall quality of life.

“If you can transfer a nerve to a unit of muscle where it’s going to arborize and remain physiologically viable, it’s a natural assumption that you will have less [pain],” Dr. Smith says. He performed this surgery for a man who had his leg amputated above the knee. “He’s doing well,” with no sign of neuroma, Dr. Smith notes. Plus, adds Dr. Smith, “When [the patient] thinks about moving his ankle up and down, he gets a muscle firing in the back of the thigh. The nerves have arborized into the muscle.” The next step is to develop the leg prosthesis and sensors required to capture those signals and turn them into movement.

Beyond the risks of the surgery itself, the main risk of the procedure is that the phantom limb pain will return or worsen for a time after surgery. Another downside is that it can take up to six months for the nerves to grow into the muscle, which can be a tense waiting time for patients, Dr. Kuiken says.

THE SENSE OF TOUCH

Dr. Kuiken’s research comes at a time when the military has made developing more natural prostheses a major goal. The “Revolutionizing Prosthetics Program” is designed to create a fully functional arm that responds to brain signals. Dr. Kuiken is working closely

with the Defense Advanced Research Projects Agency (DARPA) and surgeons at military hospitals on this goal. (DARPA is the central research and development organization for the U.S. Department of Defense, charged with finding government, academic, and private-industry researchers for research and development projects that will benefit U.S. national security.) The U.S. Army is also funding research to develop an interface for powering artificial legs, he says.

Dr. Kuiken and his team are also working to bring sensation to those prostheses. Claudia, for instance, can “feel” hand sensations in her chest (where the nerves for her amputated left arm were transplanted). The next step is developing the technology to transmit those sensations to the prosthesis.

The demand for improved prosthetics is huge. Every year, an estimated 185,000 people lose a limb to trauma or disease. Today, an estimated 1.6 million Americans are living without one or more limbs. An aging population and epidemic of diabetes, however, is expected to more than double that figure by 2050 to 3.6 million.

The computer decoding program also holds great promise for people born with missing limbs. Initially, Dr. Kuiken and his team were doubtful as to whether the surgery would work in someone who had never learned to operate a hand or wrist. To their surprise, “we found patients could operate a wrist really quite well” although they had more

trouble moving the prosthetic hand. Nonetheless, says Dr. Kuiken, “we’re pretty confident we can get [the hand] to open and close as well.” The fact that they were able to operate the prosthesis without ever having a hand or wrist “is extraordinary,” he says, and a sign of the amazing plasticity of the brain.

When Claudia was on her way to Chicago for the surgery, her pastor told the church congregation that Claudia was fine the way she was, and that the new prosthesis “will be an extra bonus for her.” Claudia remains thrilled with her new arm, which she has happily nicknamed “Bonus.” NN

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